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Impacts of freshwater impoundment in the West Loch of Pearl Harbor

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IMPACTS OF FRESHWATER IMPOUNDMENT IN THE WEST LOCH OF PEARL HARBOR

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Potable use of surface water is an old concept that deserves reconsideration in Hawai'i. Surface impoundment complements existing potable sources by preserving the sustainable yield of groundwater aquifers and capturing runoff and leakage that would otherwise be lost. Current environmental regulations at both the State and federal level dictate that alternative water sources be developed to meet future demands. The complexity of Hawaii's water rights code demands that new sources be developed through joint venture between local, State and federal government as well as private business. Local public interest in environmental issues and special interest resistance to large public works projects suggests full public participation in the planning process for these alternative sources. This will promote public acceptance or rejection of the proposal early in the process so that costly delays can be avoided later.

The objective of this thesis is to review existing data to determine the viability of capturing surface runoff from Waikele and Honouliuli Streams. Impoundment of this alternative water source, within the existing confines of West Loch, offers substantial benefits to all interested parties. Besides creating a new 25 mgd potable water supply to support future development within the Ewa Plain, it can also control non-point source pollution that is the largest remaining cause of pollution in the Pearl Harbor Estuary. This project can also do much to enhance and create new wetland habitat to support endangered Hawaiian waterfowl. By controlling sedimentation of ship channels significant savings can be realized from reduced maintenance dredging. It allows an opportunity for consolidation of existing military activities that could promote more compatible land use in rapidly developing residential areas by making land used for ordnance stowage available for military housing.

Sufficient data is available to warrant further study of this proposal. Existing water quality data on Waikele Stream suggest that it can provide a reliable source of raw water that can be treated using conventional methods to yield a high quality potable product. Impoundment of this runoff is expected to improve the quality of nine critical water quality parameters which will dictate treatment process design requirements. Preliminary estimates indicate that production cost competes favorably with other potable water production alternatives.

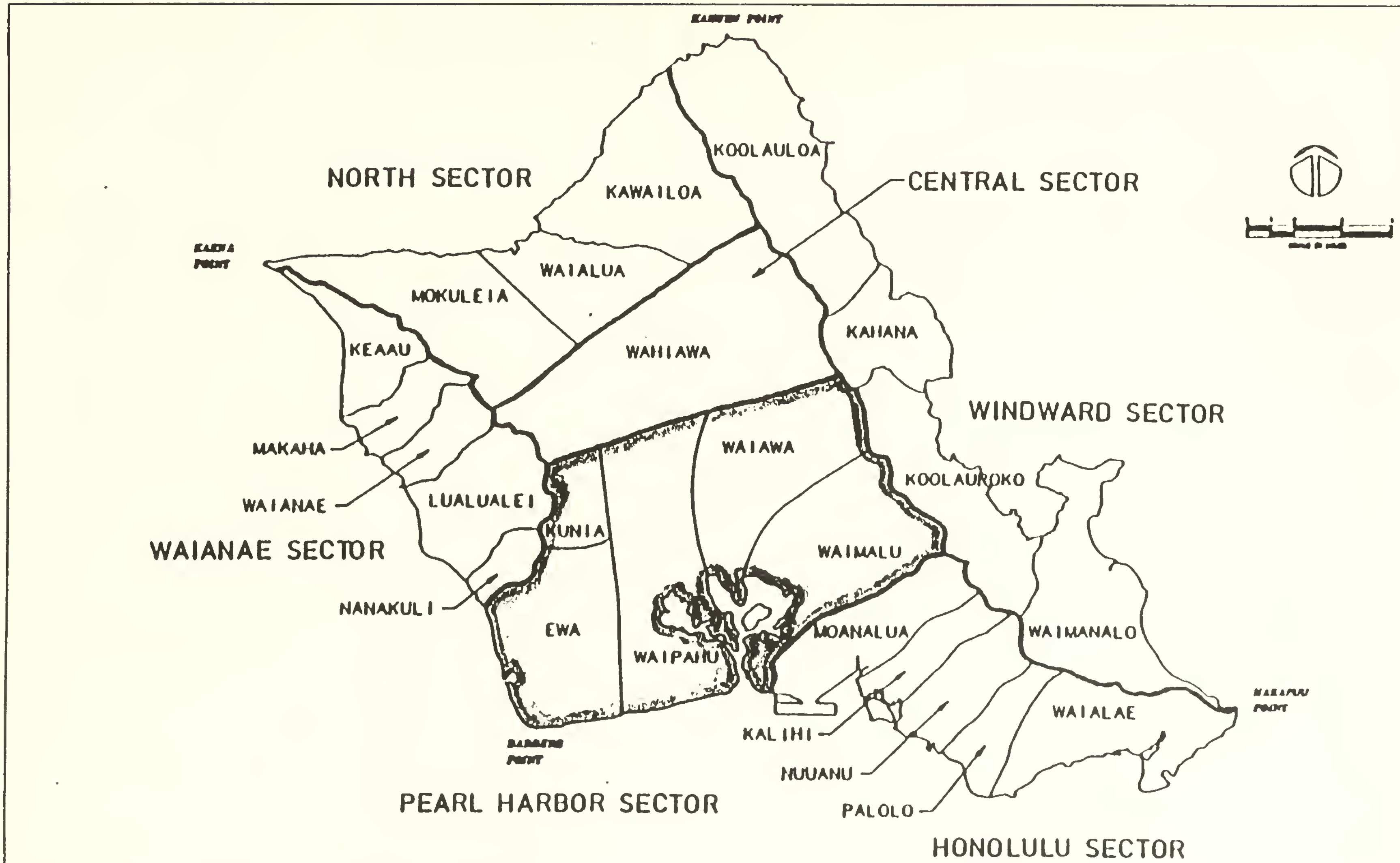
While this study is far from conclusive it does compile extensive existing data and offer a plan to gather additional information and begin a dialog with affected parties. Much of this future data gathering & research may be eligible for funding through non-point source pollution demonstration grant programs. It is the authors' hope that it will stimulate constructive dialog between potential beneficiaries, that will lead to a well-informed consensus regarding project value and cost sharing.

CHAPTER ONE:
Preservation of Paradise

THE ENVIRONMENTAL CLIMATE of OAHU

The island of Oahu is a fast growing metropolitan community rapidly approaching a population of one million people. The community is blessed with the reputation as a tropical paradise of sparkling blue waters, fresh pure trade winds, and abundant greenery. Its majestic mountains gather sufficient rainfall to sustain a large ground water supply which has supported a strong agricultural economy and sustained development. The rapid urbanization of the leeward shores has raised concerns about the sustainability of groundwater sources as the island nears its estimated supportable population. The State of Hawai'i has a strong tradition of protecting water resources through regulation of land use. The zoning of preservation lands was initiated on Oahu early in the 1920s to protect groundwater recharge areas (Lau, 1987). In 1987, after ten years of debate, the Legislature finally enacted a State Water Code. Its objective is to balance the property interests of agricultural producers and land developers with the conservation of this valuable natural resource. As a result, the Commission on Water Resource Management is responsible for allocating water resources throughout the state. Figure 1-1 shows the Pearl Harbor Ground Water Control Area (PHGWCA) which was established by the Ground Water Use Act in 1979[1]. It includes the Waimalu, Waipahu, Wahiawa, and Ewa water use districts and contains the largest groundwater body on Oahu, supplying more than 50 percent of the island's water demand (BWS, 1982 and Wilson Okamoto & Associates, 1992). Estimates of sustainable yield in this aquifer have been lowered from 225 million gallons per day (mgd) in 1988, to 197 mgd, and entirely allocated to the existing users

[1] Chapter 177, Hawaii Revised Statutes, 1986



Source: (Wilson Okamoto & Associates, 1992)

FIGURE 1-1

AQUIFER SYSTEMS

(DWRM, 1992). The Ewa Plain, which lies within this area, is designated in the City and County of Honolulu General Plan as the site of Oahu's second primary urban area (Department of General Planning, 1977). This new "Second City" has been planned by State and City officials to provide housing and jobs to support a future population estimated to reach 1,049,500 by 2010 (Hawai'i, 1988). Water demand in the Ewa area would increase over 300 percent (Wilson Okamoto & Associates, 1992). The success of this development is not only financially important to the participating developers but also vital to alleviating urgent housing, transportation, and job deficiencies for the general public. Development of an alternative water source is essential for future economic growth on Oahu.

A small group of vocal environmental populists has also launched a vigorous media and legal debate to maintain the pristine quality of local bays and beaches, as well as further their political ambitions. The main target of this campaign has been illegal discharge of sewage from the city's sewage treatment plants. These plants provide advanced primary treatment that removes about 35% of pollutants from the raw sewage before it is discharged into the ocean approximately one mile from shore. Although several studies have indicated that current water quality degradation is primarily the result of non-point pollution (Fujioa, 1990), this group contends that secondary or tertiary treatment is the only acceptable method of safely disposing of the island's sewage.

In 1972 the Federal Water Pollution Control Act mandated secondary treatment for all publicly-owned treatment facilities but in 1977 Congress acknowledged the greater assimilative capacity of the ocean by allowing the EPA to consider waivers for marine discharges. The city has spent enormous amounts of money to construct additional, advanced primary treatment plants to eliminate discharges from estuaries and embayments at Pearl Harbor and Kaneohe Bay, and improve deep ocean outfalls to

obtain EPA's waiver. If construction of secondary treatment plants can be avoided future expenditures of sewage fees can be directed at improvements to the sewage collection system that is very old and causes most of the illegal discharge.

Implementation of any major public works project has been met with significant public opposition from various factions and interest groups throughout the island. Completion of the H-3 freeway, connecting Windward and Central Oahu, has been delayed over 30 years and plans for a rapid transit system have generated additional controversy. The resentment of the local populace grows as development continues. Foreign investment, land use regulation has resulted in increasing property taxes, the most expensive housing and the highest cost of living in the nation. Consequently, fewer residents are able to afford their own home. As the 100th anniversary of the end of the Hawaiian monarchy is commemorated, renewed claims for return of ceded lands grow. They are fueled by the growing mistrust of government bred by the continuing failures of the Hawaiian Homelands Program to allocate trust lands and the perception of insensitivity to native cultural heritage and the sewage disposal controversy.

PROBLEM STATEMENT

What is the best way to resolve new demands for potable water within the Pearl Harbor Ground Water Control Area? During the past twenty years several plans have been proposed to:

reallocate existing potable supplies

use sewage effluent to augment groundwater recharge;

reuse secondary-treated effluent for crop irrigation;

treat primary effluent using biological capacity of water hyacinth prior to reuse for irrigation;

desalt existing brackish water supplies, and;

create a freshwater impoundment in West Loch.

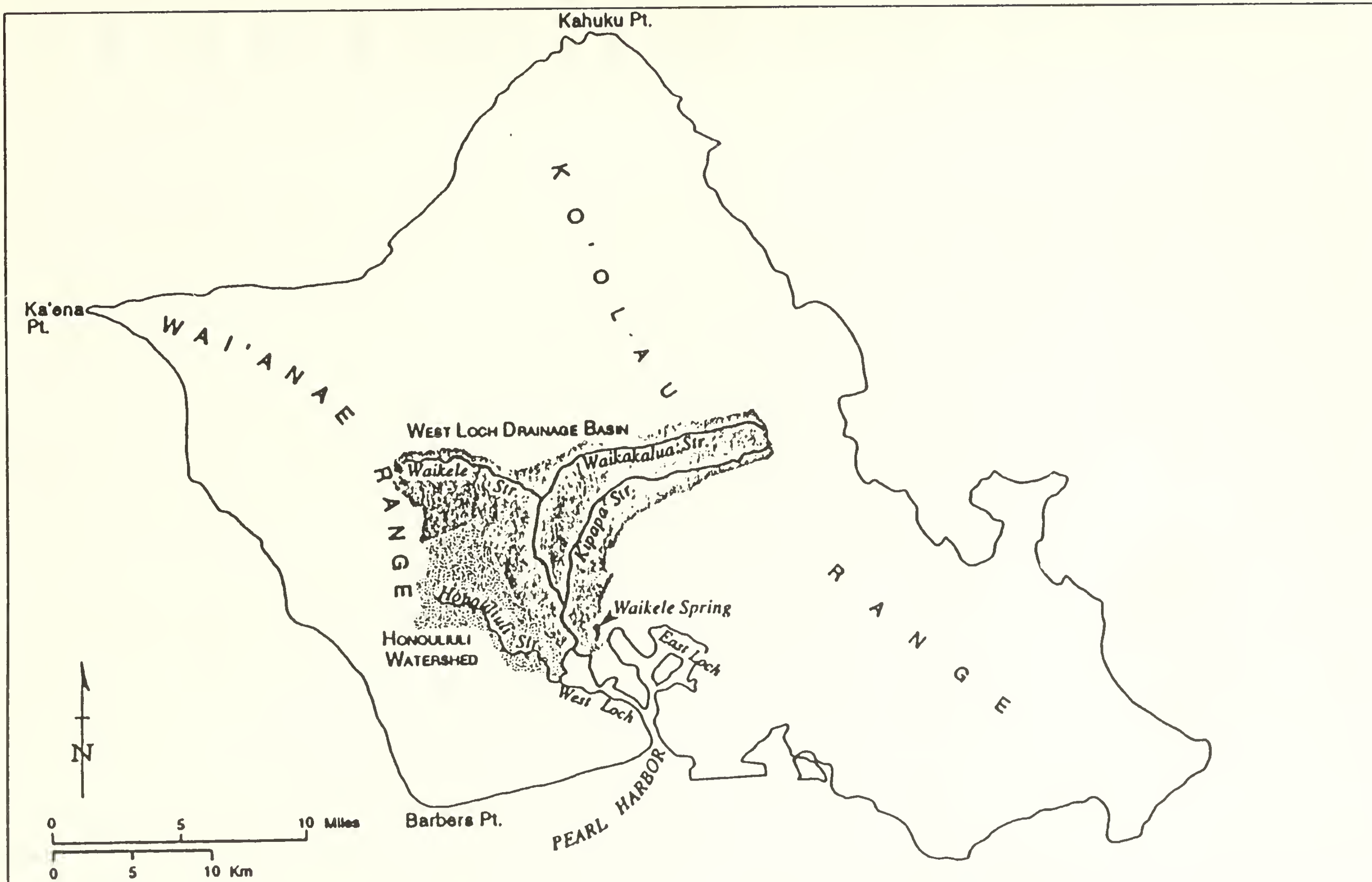
The Board of Water Supply (BWS) and the Department of Land and Natural Resources (DLNR) have advocated reallocation of potable groundwater supplies used for irrigation as a principal component of their water management plans for many years (BWS, 1975 and Wilson Okamoto & Associates, 1992). Use of sewage effluent for irrigation or recharge has been extensively researched (Lau, 1989 and Gee, 1985) and is rapidly becoming common practice in arid states (Lau, 1990 & 91). Public health officials in Hawai'i have been reluctant to adopt this practice without first providing secondary treatment (Wilson Okamoto & Associates, 1992). Research has demonstrated that Water Hyacinth ponds can be used to achieve secondary treatment standards but large land requirements make it uneconomical in Hawai'i (Okita, 1991 and Mudivarthy, 1992).

Development of the Ewa Plain is now in full swing but adequate water supplies still have not been identified to support the numerous projects under construction (Dooley, 1988 and Tillis, 1989). The BWS and State are experimenting with desalination of brackish water supplies to provide the alternative water sources for Oahu's future. In a joint venture with the James Campbell Estate, they have developed a one-mgd pilot plant that is currently in operation at Campbell Industrial Park. Initial experience indicates high production costs ($3.70/ 1000 gal). The original feasibility study (Park, 1983) estimated an adjusted 1992 cost of $0.86 /1000 gal for full scale operations (10 mgd), but experience in other plants throughout the U.S. indicate a range of $1.30 - $1.65 is more realistic (Moncur, 1992).

The diversion of surface waters for agricultural irrigation and personal consumption is an ancient Hawaiian tradition that demonstrates deep cultural respect for conservation and preservation of nature. Today surface water sources provide potable supplies for over 67 percent of the U.S. population (Davis, 1991), they only contribute 15% of Hawaii's present potable supply (USGS, 1987). No surface sources are

currently used for potable supply on Oahu. The development of alternative freshwater supply by impounding runoff from Waikele and Honouliuli Streams (Figure 1-2) was investigated by the BWS in the 1970s (Chang, 1973 and BWS, 1979). The feasibility of this concept, using alternative methods of impoundment, was studied further during the ensuing years (Murabayashi & Fok , 1983 and Fok & Murabayashi ,1991). In each study, feasibility was assessed based only on the benefits derived from irrigation use because the resulting water quality was assumed to be unfit for potable use. Furthermore, stricter monitoring and treatment requirements have been implemented for surface waters by the Safe Drinking Water Act (SDWA). This has resulted in a reluctance to develop surface sources for potable supply (Smith, 1990). In fact, impounded waters are used in 1700 cities to provide potable water for more than 55 million people in the US (Gelderich, 1980). As the result of point source controls implemented in conjunction with the Clean Water Act (CWA), the quality of impounded freshwater from Waikele Stream may well be much better than most raw water sources for municipal supplies throughout the nation.

Treatment to potable standards will certainly entail additional costs but it will also greatly increase the utility of the product. This could dramatically alter the cost / benefit analysis and result in an ultimate production cost that is significantly less than desalination of brackish water. Therefore, this thesis will explore the feasibility of impounding freshwater from Waikele and Honouliuli Streams in the West Loch of Pearl Harbor for potable use rather than irrigation. First we will identify the organizations that have an interest in this proposal. Then we will review environmental legislation that could impact how to proceed and where to seek funding. In Chapter Three the existing water quality data for Waikele Stream will be reviewed to identify critical water quality parameters that will need potable treatment . Chapter Four will explore how impoundment of surface flow can be expected to impact critical water



Source: (FWPCA, 1969) as adapted by (Fok, 1992) FIGURE 1-2. WEST LOCH DRAINAGE BASIN

quality parameters and estimate the size of the reliable supply. Then we will identify facilities that will be required to accomplish impoundment and treatment and estimate the construction cost. A plan of action will be developed in Chapter Seven to initiate additional data gathering, research and consensus building so that the ultimate feasibility of this concept can be evaluated.

"PLAYERS" IN THE PROCESS

In order to better understand the benefits and impacts of freshwater impoundment we must identify the various public and private organizations that could be affected and evaluate their potential gains and losses.

Board Of Water Supply (BWS), City And County Of Honolulu

This semi-autonomous public agency is charged by the City Charter to conserve, develop resources, and operate municipal water utilities on Oahu. It is entirely self- supporting from revenues generated from water sales. To execute these responsibilities they have the authority to issue revenue bonds for capital improvements and have the power of eminent domain (BWS, 1982). The BWS is the largest single user of groundwater in the PHGWCA. It exports 50 mgd to support shortfalls in Waianae and Honolulu. Without this augment the water demand in the primary urban area could not be satisfied. Impoundment of fresh water runoff from the Waikele/ Kipapa/ Honouliuli watersheds would prevent the loss of freshwater runoff which currently drains into and mixes with the saltwater of the Pearl Harbor estuary. This could provide as much as 25 million gallons of water each day to augment existing groundwater sources on Oahu. This new water supply would provide substantial relief to the already strained Pearl Harbor Aquifer and support ongoing development in Kapolei. Several plans have been proposed to create this freshwater impoundment in West Loch during the past twenty years, but the BWS currently favors desalination as

the principal alternative of new source development. This alternative is supported because of costly monitoring and treatment requirements mandated by the "surface water treatment rule" of the Safe Drinking Water Act which will be explored in Chapter Two.

City And County Of Honolulu, Department Of Public Works

This branch of city government is responsible for maintenance of the sewage system and operation of the publicly-owned wastewater treatment plants (WWTP) on Oahu. The Sierra Club Legal Defense Fund has filed a citizen's suit alleging thousands of violations of the CWA at the Honouliuli WWTP. A previous suit against the Sand Island plant has resulted in a negotiated settlement that requires a four year study of the health and ecological impacts of the Mamala Bay sewage outfall (Antolini, 1992). The divergent views of the interested parties have made it difficult to establish productive dialog with citizens' groups such as Save Our Bays and Beaches (SOBB). Consequently a third suit is impending at the Kailua WWTP. This situation is unfortunate because it threatens to force the expenditure of millions of dollars on improvements that will not significantly improve water quality. Several studies have indicated that the major source of near-shore pollution is runoff from breaks in sewage collection lines and nonpoint agricultural sources (Fujioka, 1990). The general public has been reluctant to accept this fact because of the poor track record established by past treatment practices which caused significant pollution in Kaneohe and Mamala Bays and Pearl Harbor. Although local newspapers have highlighted the significant improvements that have been made, the department's public credibility is still in question. An extensive baseline water quality assessment was made of Pearl Harbor prior to elimination of numerous point discharges (Morris,1973). While numerous subsequent studies support a continuing trend of water quality improvement as a result

of the department's construction of the Honouliuli WWTP, recommended follow-up water quality assessments have not been made. Implementation of a new water quality sampling program at selected stations could assess the effectiveness of twenty years of pollution abatement efforts by the city.

State Department Of Health (DoH)

DoH has overall authority for planning water quality management programs in the State. Its Environmental Management Division is responsible for water quality enforcement, environmental planning, and management of natural resources. Public criticism has demanded tighter enforcement of WWTP's throughout the State. The department has demonstrated a progressive approach in protecting the public health and environment, but also recognizes the importance of balancing these concerns against the cost to the taxpayer. Consequently, to minimize overhead costs, monitoring efforts have been limited to satisfying specific requirements of various environmental regulations rather than continuous monitoring. This has made a greater percentage of the operating budget available for abatement actions but has also made it more difficult to demonstrate the beneficial results of these efforts because water quality data is limited. A comprehensive water quality sampling program could be initiated within the Pearl Harbor estuary using a limited number of stations from the 1973 baseline study. This would minimize testing costs but still allow a statistically significant assessment of water quality improvements during the past twenty years. Such a study could restore public confidence in past pollution abatement actions and reinforce the argument for secondary treatment waivers if specific water quality improvements can be substantiated. The result would allow the expenditure of hundreds of millions of dollars on sewage collection systems rather than costly secondary treatment plants that would only marginally improve water quality.

State Department Of Agriculture (DoA)

This agency is concerned with protecting the economic viability of existing growers and promoting the diversification of new crops. Environmental Protection Agency (EPA) statistics indicate that these agricultural sources cause 80-90% of water quality problems in Hawai'i (Liu, 1992). Pesticide contamination of wells in Mililani and Waipahu caused substantial public concern in 1983 (Lau, 1987). Uncertainty over allowable maximum contaminant levels (MCL) has resulted in expensive treatment of groundwater to remove minute quantities of pesticides. Subsequent studies have indicated that this type of contamination can be prevented by proper application of agricultural chemicals(Oki, 1990). Recent research indicates that past water pollution controls may have been misdirected. EPA has consequently refocused efforts to control non-point sources. DoA is actively involved in a cooperative program with the USDA, Soil Conservation Service (SCS) to improve agricultural practices that are responsible for non-point source pollution (Tulang, 1992). It appears that freshwater impoundment could also provide an opportunity to demonstrate some innovative techniques for controlling non-point sources of water pollution by creating and enhancing wetlands surrounding the stream mouths. Furthermore, the forty year water quality record from Waikele Stream (USGS Gaging Station #162130000) could be used with the 1973 baseline study and a new sampling program to evaluate the effects of non-point source on the ultimate water quality of Pearl Harbor.

State Department Of Land & Natural Resources, Water Resources Management Division (DWRM)

This organization serves as the staff for the State Water Commission. In this capacity it works closely with DoH to develop the State Groundwater Protection Program. This has resulted in the creation of the PHGWCA. The Commission is

responsible for ensuring that water resources are appropriately allocated to all users. Regulations have been established that have reallocated available groundwater to existing users based on lowered estimates of the sustainable yield. The users are required to develop their own Water Use Plans. DWRM is working with the Ewa Plain Water Development Corporation to find alternative sources of water to support new water requirements for Kapolei, Oahu's "Second City". One of the initiatives that has resulted is the demonstration desalination project. While desalting has been used on a large scale in some nations, it is substantially more expensive than groundwater sources (almost twice the cost). Development of a more cost effective alternative would be welcomed by users and regulators alike because the need for these expensive new sources is hotly contested by developers (Dooley, 1989 and Tillis, 1988).

State Office Of Planning (OSP)

New, affordable housing, preservation of existing jobs and creation of new middle income jobs are Hawaii's highest priorities. Preservation of water resources is vital to all of these goals. Balanced growth is also an important consideration because of environmental and cultural concerns. As the State's strategist for implementing long range objectives, OSP is interested in supporting innovative solutions. Past experience supports public involvement in the planning process but this public input has also proven to be time consuming. This staff is in the best position to recommend appropriate levels of public involvement given the time constraints that are imposed by the situation. They are also experienced in coordinating grant applications for federal funding.

Ewa Plain Water Development Corporation (EPWDC)

This corporation has been organized by the Campbell Estate to reassess net water demands for new projects and provide solutions to water shortfalls in this area. It represents Haseoka, Gentry, Horita and many other smaller development companies. The current master plan for Kapolei relys on the use of local groundwater sources to satisfy new demand (Helber, 1992). This can only be accomplished if sufficient agricultural lands (which use extensive quantities of potable water) are converted to urban uses that implement strict conservation measures. The Water Commission's current allocation in the PHGWCA does not support this reallocation concept. Consequently, EPWDC is currently reviewing the water projections of their Water Master Plan (Belt Collins, 1987). Recent declines in the Japanese stock market have threatened financing for many of the projects proposed for the Ewa Plain. If this water allocation discrepancy is not resolved or an economically viable alternative water supply is not quickly developed, millions of dollars could be lost and thousands of families will continue to be deprived of housing and new jobs.

The Pearl Harbor Estuary Program Interagency Committee

This committee formed during the summer of 1990 to address the pollution problems associated with the Pearl Harbor Watershed. Sedimentation and the problems it causes is their foremost interest. This group is coordinated by the South and West Oahu Soil and Water Conservation Districts. Participants include representative from Federal, State local and governmental agencies as well as private organizations. Through their cooperative efforts and joint funding a grant proposal has been prepared for funding under § 319 of the Clean Water Act (CWA). This group is the logical choice to coordinate initial review and subsequent data gathering and research if further planning is warranted.

Oahu Sugar Company

Sugar production is the most intensive water user in the Ewa Plain but much of it's agricultural land is rapidly being converted to urban use. Environmental controls established by the CWA have increased sugar production costs, making Hawaii's largest agricultural crop much less profitable. This company is the largest user of water in the PHGWCA and recent reductions in water allocations are sources of great concern. The company is very reluctant to convert from existing groundwater to alternative supplies because substantial capital investments have been made to develop this source (Oahu Sugar Co., 1985). There is very little incentive in using a surface water source that will require new and expensive distribution lines to irrigate crops. The proposed use of sewage effluent as a replacement for potable water used for irrigation raises potential product liability as well as technical implementation questions.

Sierra Club Legal Defense Fund (SCLDF)

This organization is a private, non-profit corporation that has recently established an office in Hawai'i to represent the "public interest" in environmental issues. They have represented Hawaii's Thousand Friends and Save Our Bays And Beaches(SOBB) in several CWA citizen suits against the City. SCLDF has been criticized by the local scientific community because much of their litigation has been supported by mainland studies rather than local research. Because of their contacts with independent mainland experts SCLDF may be a likely choice to represent the "public interest" in a scoping assessment of this proposal for surface impoundment in West Loch as an alternative potable water source.

Commander, Naval Base Pearl Harbor

US Navy use of Pearl Harbor began well before annexation. The first formal land acquisition was accomplished by a treaty of reciprocity signed in 1876 by the kingdom of Hawai'i and the United States. The Act of July 7, 1898, ceded lands of the Republic of Hawai'i to the United States.[2] Title acquisition to the property that now comprises the Naval Magazine Lualualei (NAVMAG) began in 1909 using civil proceedings based on Eminent Domain. Subsequent holdings were acquired by a combination of fee simple purchase, condemnation, land exchange, and executive order.[3] West Loch is designated as a Restricted Access Area because of the handling and storage of ammunition at naval activities located along its shoreline. It lies within the Pearl Harbor Naval Defensive Sea Area (NDSA) established by President Roosevelt prior to World War II, through issue of Executive Order (EO) 8143.[4] These evolutionary events have established the Department of the Navy as the caretaker of this federal land, including the waters and submerged lands of West Loch.

The Pearl Harbor Estuary has played a significant role not only in the cultural heritage of Hawai'ians but also in the growth of sugar and pineapple production, the economic development of Oahu and the State of Hawai'i, as well as the defense of our nation. Without question these uses contributed to a significant decline in water quality throughout the estuary during the mid-1970s. As caretaker of these public lands, the US Navy is committed to a program of environmental restoration and preservation. Therefore any proposal that alters this environment must consider long-term ecological impacts as well as economic value. Unfortunately the public perception of the Navy's

[2] 30 Stat. 750. 1898

[3] Civil Nos. 47, 249, 311, 465, 466, 502, 520, 522, 526, 575, 80-0504; Purchases: Dowsett Co. & Campbell Estate; GEO Nos. 1284 &1681; Land Exchange with Hawaii Meat Co.

[4] 3 CFR 504 (1938-1943). For two opposing views of the ensuing property rights see Carl J. Woods, *State and Federal Sovereignty Claims over the Defensive Sea Areas in Hawaii*, 39 Naval Law Review and Jeffrey C. Good, *State-Federal Conflict over Naval Defensive Sea Areas in Hawaii*, unpublished.

environmental record has been distorted by publicity about the large number of hazardous waste sites on military installations throughout the nation. Local environmentalists have used the recent 50th anniversary of the attack on Pearl Harbor, to focus on the environmental damage to the estuary and the nomination of six sites within the naval base to the EPA Superfund list (Tummons, 1991). The Navy wants to reestablish their environmental record and demonstrate a willingness to cooperate with local agencies, if the solution will not interfere with the military mission of the naval base.

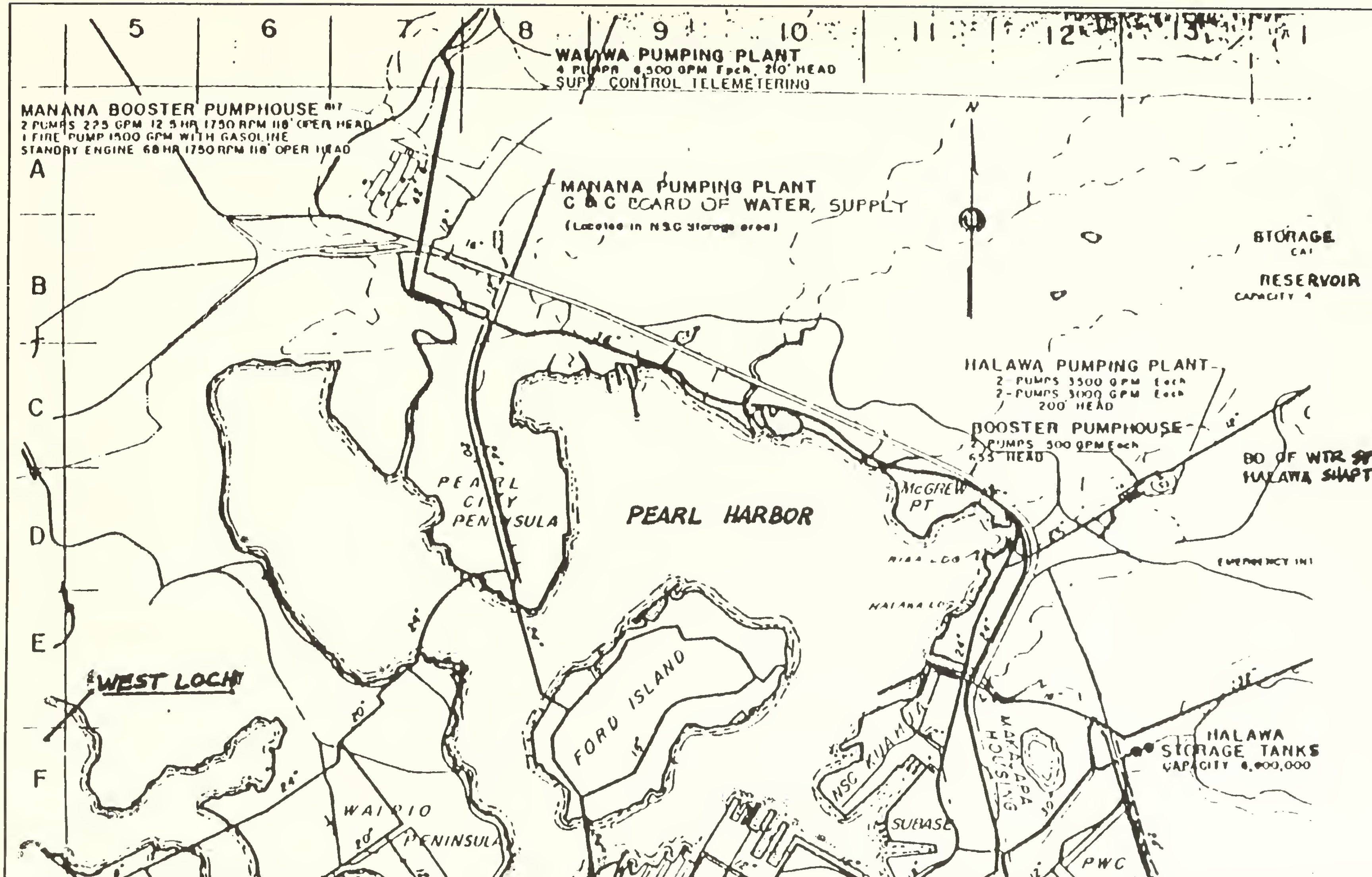
Pacific Division, Naval Facilities Engineering Command (PACDIV), Naval Civil Engineering Laboratory (NCEL), and Naval Energy & Environmental Support Activity (NEESA)

These engineering activities build and maintain shore facilities throughout the island and lead the Navy environmental program. For the past twenty years these organizations have worked actively with local government to improve the water quality of Pearl Harbor. Many sources of past pollution have been eliminated by these cooperative efforts (Grovhoug, 1992). Past water quality studies have indicated that the largest remaining cause of pollution is sedimentation caused by urban development and agricultural practices (PACDIV, 1977). Impoundment could also help control the pollution transported by sedimentation. This would reduce the frequency of channel dredging in West Loch.

Millions of dollars have been spent to identify and assess the hazards of former waste disposal sites. Clean-up efforts continue but progress is very slow because standards continue to change as new research data becomes available (Sauerwein, 1992). Although harbor sediments do exceed some EPA standards for heavy metal contamination, initial assessment indicates that levels are not high enough to warrant further action based on the EPAs cleanup criteria (NEESA, 1983).

Substantial restructuring of military forces and drastic budget cuts make it imperative to operate shore facilities more efficiently. Military housing is still a high priority in Hawai'i because of the high cost of living. Appropriately sited federal land has been the greatest obstacle to constructing adequate housing. Ford Island has been proposed as one site to provide a portion of this requirement (PACDIV, 1990). Freshwater impounded in West Loch would be conveniently located to support the proposed Navy development on Ford Island (PACDIV, 1990). Impoundment could also improve access to the Waipio Peninsula if an earthen dam were to be constructed. This could allow consolidation of NAVMAG activities and free land to satisfy the remaining military housing shortages.

Perhaps most importantly, impoundment of freshwater in West Loch could provide a back-up for existing Navy water supplies. The Navy's Waiawa Shaft (Figure 1-3) is the largest single source of groundwater on Oahu. Its daily production of 14 mgd represents 62% of the Navy's water allocation. In the late 1970s this source began experiencing elevated levels of salinity (Nakamoto, 1980). This was attributed to a change in irrigation practices in the cane fields which are above this well field. When these fields returned to irrigation using freshwater, the chloride levels of the Waiawa water returned to normal levels (USGS, 1983). This underscores the importance of protecting this source from groundwater contamination. While no subsequent problems have been experienced, these cane fields are now undergoing conversion to residential use. This raises new concerns of potential contamination from commonly used domestic pesticides. Application practices of these pesticides vary greatly and are difficult to control . Although recent studies indicate that chemical transport is not expected to result in contaminate concentrations that exceed the National Primary Drinking Water Standards (Oki, 1990), the loss of the Waiawa source would severely restrict Navy potable water production capability and could impact



Source: (PWC Pearl Harbor DRWG NO. 956688)

FIGURE 1-3 LOCATION of WAIAWA SHAFT

production capacity of BWS wells adjacent to other Navy sources in Halawa Valley if increased pumping were required to compensate for the loss of the Waiawa shaft.

Commanding Officer, Naval Magazine Lualualei

Dramatic changes in the world political structure have resulted in substantial restructuring of military forces and drastic budget cuts. The Navy is actively seeking ways to operate more efficiently. If not carefully planned, impoundment of West Loch could result in substantial interference with the Navy's mission. This mission includes ordnance support for all DoD activities on Oahu. Support is provided to Army units at Schofield Barracks, tactical squadrons based at Hickam Air Force Base and Marines from Kaneohe Air Station. Support of naval activities is much broader than just locally homeported ships and submarines from Pearl Harbor and air squadrons from Barbers Point Naval Air Station. Fleet activities throughout the Pacific Ocean are supported by ammunition ships that are restocked at the NAVMAG (PACDIV, 1989 & 1976). This mission has become more important and equally more complex because of restructuring. Construction of an impoundment which creates a new access to Waipio Peninsula may allow a consolidation of facilities that are presently conducted at three separate locations on Oahu. Unfortunately, an impoundment may not be compatible with existing operational and ordnance safety requirements. This may well be the determining factor regarding the feasibility of this proposal.

University of Hawai'i, Water Resources Research Center (WRRC)

This organization focuses the research efforts of university scientists and engineers from the private and public sector on water resources and waste treatment. WRRC provides an important source for technology transfer to local governmental agencies. Their studies support the use of treated sewage effluent to augment

groundwater recharge; treatment of primary effluent using the biological capacity of water hyacinth prior to reuse for irrigation, and reuse of secondary effluent for crop irrigation. While these methods have been incorporated in some State and local policy documents, the DoH has been reluctant to approve them for implementation even though they have been studied or successfully implemented throughout the world. All of these concepts could conceivably be used in conjunction with a surface impoundment in West Loch. The multi-disciplined staff is well suited to coordinate additional data collection and research for this project.

SUMMARY

It is readily apparent that these groups represent a wide variety of diverse interests. Benefits derived by one group could conceivably adversely impact others, but one advantage is common to all. Everyone will gain from the development of an additional source of potable water within the Ewa Plain. The challenge then is to develop a plan which will maximize the benefits to the greatest number of interested parties, so that development costs can be equitably distributed. Every major water resources project is affected by the proliferation of environmental legislation. It not only can alter design concepts but can also provide additional potential sources of funding. These impacts will be addressed in the next chapter.

REFERENCES

Antolini, D., February 27, 1992. "The Mamala Bay Settlement and the Sierra Club Legal Defense Fund's Involvement in Water Quality Issues in Hawai'i". Water Resources Research Center Seminar, University of Hawai'i Manoa, Honolulu, Hawai'i.

Belt Collins & Associates, August 1987. *Ewa Water Master Plan (Revised).* Ewa Plain Water Development Corporation, Honolulu, Hawai'i.

Board of Water Supply(BWS), July 31,1975. *Oahu Water Plan.* City and County of Honolulu, Hawai'i.

BWS , July 20, 1979. *West Loch Impoundment Utilizing Water From Waikele and Waiawa Stream.* City and County of Honolulu, Hawai'i.

BWS, July 1982. *Oahu Water Plan, Summary Report.* City and County of Honolulu, Hawai'i.

Chang, J.Y.C., 1973. *"A Study of West Loch Impoundment."* Unpublished Report. Division of Planning, Resources and Research, Board of Water Supply, City and County of Honolulu, Hawai'i.

Chief of Naval Operations (CNO), May 2, 1986. <u>Environmental and Natural Resources Protection Manual</u>, OPNAVINST 5090.2

Davis, M.L. and Cornwell D.A., 1991. <u>Introduction to Environmental Engineering</u>, McGraw-Hill, Inc., St. Louis, Missouri

Department of General Planning, 1977. *"General Plan: Objectives and Policies".* City and County of Honolulu, Hawai'i.

Department of Health (DOH), 1979 *"Water Quality Management Plan for the City and County of Honolulu"*, State of Hawai'i

Department of Health (DOH), July 1989 *"Hawaii's Assessment of Non-point Source Pollution Water Quality Problems"*, State of Hawai'i

Department of Land and Natural Resources (DLNR), June 1984. "Water Management Plan for the Pearl Harbor Ground Water Control Area". Circular 101. State of Hawai'i

Division on Water Resource Management (DWRM), February 25,1992. *"Pearl Harbor Water Management Area Allocation Plan"*, Department of Land and Natural Resources, State of Hawai'i.

DWRM(a), February 25,1992. *"Proposed Additional Water Demand for New Developments in the Pearl Harbor Water Management Area"*, Department of Land and Natural Resources, State of Hawai'i.

Dooley, J. 16 October 1989. “Ewa water could be gold Haseko’s money can’t buy”, Honolulu Advertiser, Honolulu, Hawai'i.

Environmental Center, University of Hawai'i, May 19, 1978. *Baseline studies and Evaluation of the Physical, Chemical, and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Hawai'i.* Pacific Division Naval Facilities Engineering Command, Pearl Harbor, Hawai'i.

EPA, August 1971. *Addendum to Report on Pollution of the Navigable Waters of Pearl Harbor.*

Federal Water Pollution Control Administration, Pacific Southwest Division, October 1969. *Report on Pollution of the Navigable Waters of Pearl Harbor.* U.S. Department of the Interior.

Fok , Y. -S. and Murabayashi, E.T. September, 1992. *"Impoundment of Stream Flow in West Loch, Pearl Harbor, Oahu, Hawai'i: A Feasibility Study".* Technical Report #192. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Fujioka, R.S., December 1990, *"Evaluation of Clostridium Perfringens as a Suitable Indicator for Recreational Water Quality Standards".* Year One Project Completion Report to State Department of Health. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Gee, H.K., Murabayashi, E.T., Young, R.F, September 1985. *" Wastewater Irrigation for Alfalfa, Guinea Grass, and Papaya Production in Hawai'i".* Technical Report #170. Geldreich, E.E., Nash, H.D., Spino, D.F., and Reasoner, D.J., January, 1980. *"Bacterial Dynamics in a Water Supply Reservoir: A case Study".* American Water Works Association Journal, Vol. 72:1, Denver, Colorado

Hawai'i Department of Business and Economic Development, November, 1988. *"Population and Economic Projections for the State of Hawai'i to 2010 (Series M-K)".* Honolulu, Hawai'i.

Helber, Hastert & Kimura, Planners. *"Kapolei Area Long Range Master Plan".* The Estate of James Campbell, Ewa, Oahu, Hawai'i.

Lau, L.S., Wu, I.-P., Gee, H.K., February 7-8, 1991. *"A New Drip-Irrigation Technology for Wastewater Reuse".* 13th Annual Conference, Hawai'i Water Pollution Control Association, Sheraton Waikiki Hotel, Honolulu, Hawai'i.

Lau, L.S., February 8, 1990. *"A Water Reclamation facility for Ewa: Recycling Effluent into Assets and Benefits".* 12th Annual Conference, Hawai'i Water Pollution Control Association, Sheraton Waikiki Hotel, Honolulu, Hawai'i.

Lau, L.S., Hardy, W.R., Gee, H.K., Moravik, P.S., Dugan, G.L., August, 1989. *"Groundwater Recharge with Honouliuli Wastewater Irrigation: Ewa Plain Southern Oahu, Hawai'i"*. Technical Report #182. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Lau, L.S. and Mink, J.F., August 1987. *"Organic Contamination of Groundwater: A Learning Experience"* Journal of American Water Works Association. Vol. 79(8)

Liu, Ed, March 19, 1992. "Clean Water Act Water Quality Management and Monitoring in the 1990s". EPA Region IX, Water Management Division, Monitoring Coordinator. Water Resources Research Center Seminar, University of Hawai'i Manoa, Honolulu, Hawai'i.

M&E Pacific, Inc., August 1983. *Environmental Impact Assessment for the Proposed Pearl Harbor Dredging and Disposal.* Pacific Division Naval Facilities Engineering Command, Pearl Harbor, Hawai'i.

Moncur, James, Gee, H. and Gogineni, R., September 3, 1992. "The Ewa Demonstration Desalination Experiment: A Preliminary Report". Water Resources Research Center Seminar, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Morris, D.E., Surface, S.W., and Murray, J.P., 1973. *Navy Environmental Protection Data Base: Completion Report for the Pearl Harbor, Hawai'i Study Covering the Test Period through Calendar Year 1972.* Naval Civil Engineering Laboratory, Port Hueneme, California

Morris, D.E. and Youngberg, A.D., April 1972. *Methods of Collection and Reporting of Sediment Samples from Pearl Harbor. EPDB 73-001.* Environmental Protection Data Base Office, Pearl Harbor Division, Naval Civil Engineering Laboratory, Port Hueneme, California

Murabayashi, E.T. and Fok , Y. -S. 1983. "Stream-water storage in the ocean by using an impermeable membrane". Technical Report #152. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Mudivarthy, Srinivas, February 27, 1992. *" Economic Analysis of Water Hyacinth-based System verses Conventional Treatment System for Secondary Treatment"*. Water Resources Seminar, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Nakamoto, W.S., August 8, 1980. *"Water Use Plan for the Pearl Harbor Groundwater Control Area, Pearl Harbor Hawai'i"* Public Works Center, US Navy, Pearl Harbor Hawai'i.

Naval Energy and Environmental Support Activity (NEESA), October 1983. *"Initial Assessment Study of Pearl Harbor Naval Base, Oahu, Hawai'i"*. NEESA Report 13-002. US Navy, Port. Hueneme, California.

Oahu Sugar Company, Ltd., March 1985. *"Water Management Plan for the Recertified 92.5 mgd Preserved Use Withdrawals from the Pearl Harbor Groundwater Control Area"*. Honolulu, Hawai'i.

Okita, R.H., May 1991. *"Use of Water Hyacinth to Provide Secondary Treatment of Wastewater from the Honouliuli Sewage Treatment Plant"*, Graduate Thesis, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Oki, D.S., Miyahira, R.N., Green, R.E., Giambelluca, T.W., Lau, L.S., Mink, J.F., Schneider, R.C. and Little, D.N., March 1990. *"Assessment of the Potential for Groundwater Contamination due to Proposed Urban Development in the Vicinity of the U.S. Navy Waiawa Shaft, Pearl Harbor, Hawai'i"*. Special Report 03.02.90, Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Pacific Division Naval Facilities Engineering Command (PACDIV), August 1990. *"Final Environmental Impact Statement for Proposed Developments At Naval Base Pearl Harbor, Oahu Hawai'i","* US Navy, Pearl Harbor, Oahu, Hawai'i.

PACDIV, 18 December 1989. *""Revision 1 to Master Plan for Naval Magazine Lualualei","* US Navy, Pearl Harbor, Oahu, Hawai'i.

PACDIV, 06 February 1984. *""Pearl Harbor Naval Complex - Master Plan"."* US Navy, Pearl Harbor, Hawai'i.

PACDIV and Commandant, Fourteenth Naval District, October 13-14, 1977, *"Navy Action '77: Environmental Conference on Erosion and tributary Flow","* US Navy, Honolulu, Hawai'i.

PACDIV, 11 June 1976. *""Master Plan for Naval Magazine Lualualei", "* US Navy, Pearl Harbor, Oahu, Hawai'i.

PACDIV and Commander, Naval Base , Pearl Harbor, August 1971, *Pollution Status and Control Report, Demonstration Program for Pearl Harbor Area, Oahu, Hawai'i.* ," US Navy, Pearl Harbor, Oahu, Hawai'i.

Park Engineering, January 1983. *"Pearl Harbor Brackish Water Study"*, Board of Water Supply, City and County of Honolulu, Hawai'i.

Sauerwein, R.P., December, 1991. *"Progress from Plight: The Navy's Installation Restoration Program on Oahu, Hawai'i".* American Planning Association Student Essay Contest, Honolulu, Hawai'i.

Smith, C.W., August, 1990. *"Hawai'i Stream Assessment".* Department of Land and Natural Resources. Commission on Water Resource Management, State of Hawai'i.

Stein, M., June 5-6, 1972. *"TECHNICAL SESSION: In the Matter of Pollution of the Navigable Waters of Pearl Harbor and its Tributaries-Hawai'i".* Transcript of Proceedings

Stein, M., October 21-22, 1971. *"PROCEEDINGS: In the Matter of Pollution of the Navigable Waters of Pearl Harbor and its Tributaries-Hawai'i".* Transcript of Proceedings

Strother, M.W., Winters, P.R. and Cosenza, J.P. October 1972. *Pollution Source and Environmental Resource Survey, Oahu Hawai'i Complex, EPDB 72--21.* Environmental Protection Data Base Office, Pearl Harbor Division, Naval Civil Engineering Laboratory, Port Hueneme, California

Teas, H. J., 01 March 1988. *""Evaluation of A Plan for Diversion of Waikele Stream Water for Irrigation by Use of Membrane Structures"* Appendix A, Technical Report #192. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Teas, H. J., 01 March 1988. *""Environmental Impact Assessment of the Proposed Coastal Impoundment Plan".* Appendix B, Technical Report 192. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Tetra Tech Inc., September 1977. *Ocean Disposal of Harbor Dredged Materials in Hawai'i, Final Report.* US. Army Corps of Engineers, Ft. Shafter, Hawai'i.

Tillis, V. July 1988. "Second City: Already Under Way on West Oahu Plain", Building Industry Digest, Vol. 34, No. 3, Honolulu, Hawai'i.

Tulang, M., April 16, 1992. "Non-Point Source Pollution Programs". Water Resources Research Center Seminar, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Tummons, P. December 1991. Environment Hawai'i, Vol. 2, No. 6. Honolulu, Hawai'i.

United States Geological Survey (USGS), 1981. *"Summary of Available Data on Surface Water, State of Hawai'i, Volume 4"*. Open-File Report 81-1056. US Department of Interior, Honolulu, Hawai'i.

United States Geological Survey (USGS), 1983. *"Effects of Pumpage, Irrigation Return and Regional Groundwater Flow on Water Quality at Waiawa Water Tunnel"*. Water Resources Investigation Report 83-4097. US Department of Interior, Honolulu, Hawai'i.

United States Geological Survey (USGS), 1987. National Water Summary 1987 - Water Supply and Use: Hawai'i, US Department of Interior.

Wilson Okamoto & Associates, Inc.. May 1992. *Oahu Water Management Plan.* Review Draft. Commission on Water Resource Management, Department of Land and Natural Resources, State of Hawai'i.

CHAPTER TWO
Considerations of Environmental Law

The past twenty years have witnessed an enormous growth of legislation directed at alleviating or preventing damage to the environment. The effectiveness of these laws is hotly contested by advocates for all perspectives of the endless spectrum of environmental issues. Most can agree that they have done much to change the way large infrastructure projects are planned and executed (Work, 1989). The application of environmental law on a federal facility is limited by the doctrine of Sovereign Immunity and the Supremacy Clause[5] . Sovereign Immunity simply stated, frees the government of the United States from legal suit unless Congress specifically waives this immunity as a part of some specific enabling legislation. The Supremacy Clause establishes superiority of Congressional legislation over state law. The effect of these two policies is that federal activities are exempt from state environmental regulation unless specifically enjoined by corresponding congressional legislation. The degree that Congress has been willing to exempt federal activities varies greatly as one examines the various environmental laws. Now we will explore the applicable legislation that might impact how construction of an impoundment in West Loch might be accomplished.

NATIONAL ENVIRONMENTAL POLICY ACT
42 USCA §§ 4321- 4370c

The foundation of environmental legislation in the United States is the National Environmental Policy Act (NEPA). Since its enactment on January 1, 1970, NEPA has forced federal agencies to change the way that they evaluate alternative means of conducting government business. § 4331(a) recognizes "the critical importance of restoring and maintaining environmental quality to the overall welfare and development

[5] Art. VI, US Constitution

of man, declares that it is the continuing policy of the Federal Government...to use all practical means...to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic and other requirements of present and future generations".

§ 4331 (b) goes on to enumerate that these programs should:

> (1) fulfill the responsibilities of each generation as trustees of the environment for succeeding generations;
> (2) assure... safe , healthful, productive, and esthetically and culturally pleasing surroundings;
> (3) attain the widest range of beneficial uses of the environment without degradation;
> (4) preserve important historic, cultural and natural aspects of our national heritage;
> (5) achieve a balance between population and resource use which will permit a high standard of living and a wide sharing of life's amenities; and
> (6) enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

These broad objectives establish useful goals for the West Loch impoundment proposal and serve to emphasize the important contribution it can make to our national environmental policy.

NEPA also establishes the requirement for an Environmental Impact Statement, a mechanism in § 4332(C), to ensure that these policy goals are incorporated into the planning process of all federal agencies[6]. These agencies were initially reluctant to embrace this requirement for a wide variety of reasons. This resulted in numerous litigation's of the threshold questions which determine the applicability of the EIS for various situations.[7] These court actions have resulted in a clearer understanding of the

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[6] EO 11514 of March 5, 1970; 35 FR 4247; 3 CFR 902 (1966-1970) further reinforces the environmental responsibilities. Section 1. Policy." ...Federal Agencies shall initiate measures needed to direct their policies, plans and programs so as to meet national environmental goals."

[7] MAJOR FEDERAL ACTION SIGNIFICANTLY AFFECTING ENVIRONMENT:
Hanley v. Kleindienst, 471 F. 2d 823,(2d Cir. 1972), *cert. denied*, 412 US 908 (1973);

EXEMPTIONS:	*Andrus v. Sierra Club*,442 US 347 (1979);
SCOPE:	*Vermont Yankee Nuclear Power Corp v. Natural Resources Defense Council, Inc.*, 435 US 519 (1978);
PROGRAM EIS:	*Kleppe v. Sierra Club*, 427 US 390 (1976);
ADEQUACY:	*Robertson v. Methow Valley Citizens Council*, 109 S. Ct. 1835 (1989);

requirement and a broader acceptance of the practice. Today NEPA has achieved its stated goal to give the environment equal consideration with economic and technical concerns in the decision making process The Department of Defense (32 CFR 214) and the Department of the Navy (32 CFR 775) have both published regulations which amplify the President's Council On Environmental Quality, Guidelines for EIS preparation (40 CFR 1500-1508). These rules govern EIS preparation for this impoundment proposal. Figure 2-1 provides a graphical representation of the three possible ways to satisfy NEPA requirements. §775.6(e)(2) precludes the use of a categorical exclusion and the preparation of an Environmental Assessment (EA) is not appropriate because the conversion of West Loch from a saltwater estuary to a freshwater impoundment will have obvious impacts on sealife. An EIS is necessary to determine if significant impacts are likely.

ENDANGERED SPECIES ACT 16 USCA §1531-1544

The Endangered Species Act (ESA) establishes two broad duties for federal facilities in §1531(c):

> (1) seek to conserve endangered species and threatened species, and
> (2) cooperate with State and local agencies to resolve water resources issues.

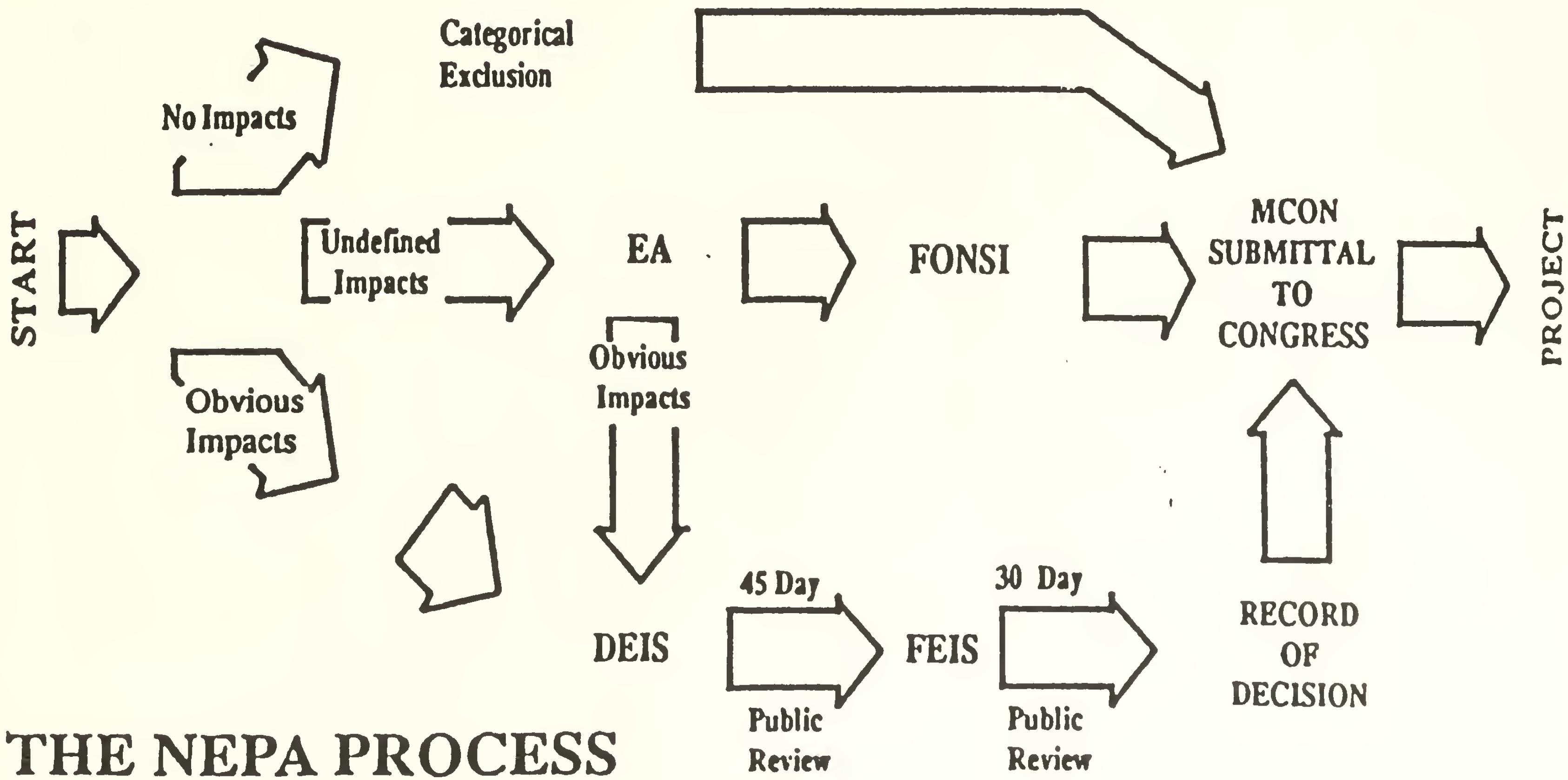
Both of these are pertinent motivators for further consideration of a freshwater impoundment. §1536(a)(1) requires agency to:

> ...in consultation with the Secretary [of Interior or Commerce] utilize their authorities... by carrying out programs for the conservation of... species listed in §1533

§1536(a)(2) further defines the Federal agencies responsibility to ensure that any action authorized funded or carried out:

> ...is not likely to jeopardize the continued existence of any endangered or threatened species ...or result in the destruction or adverse modification of [critical habitat].

Sierra Club v. Morton, 510 F. 2d. 813 (5th Cir. 1975);
Sierra Club v. Peterson, 717 F. 2d. 1409 (DC Cir. 1983);
OVERSEAS APPLICATION: *Greenpeace USA v. Stone*, 748 F. Supp. 1454 (D. Haw. 1990).



Source: (PACDIV, 1992)

FIGURE 2-1

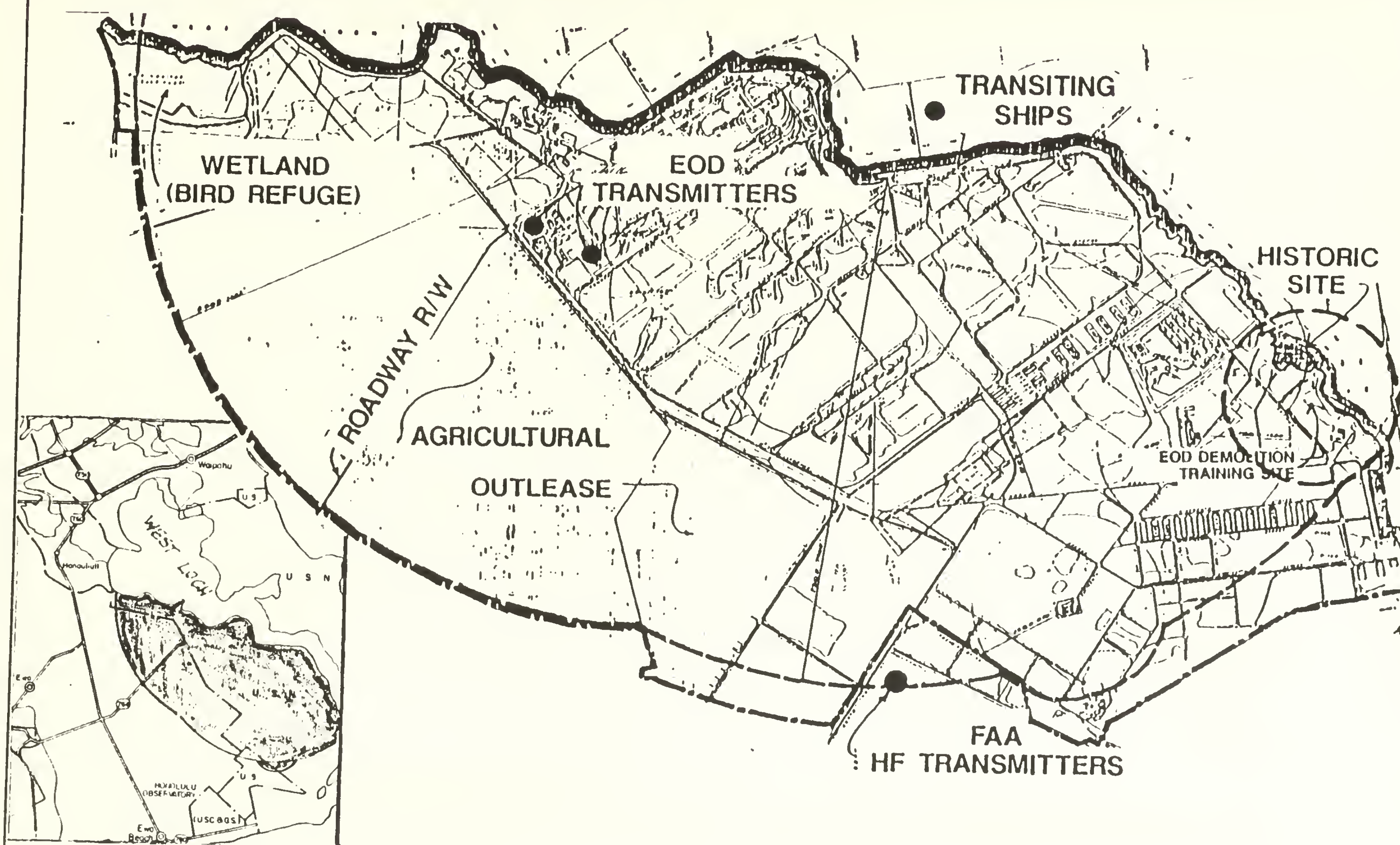
The physical setting and expected impacts of this plan on biota in West Loch have received preliminary evaluation (Teas, 1988 a&b). There are no threatened or endangered land mammals or fish in the West Loch area. Two listed species of plants are known to exist within the Ewa Plain, but none have been observed adjacent to the area of the West Loch impoundment. The former Salt Evaporator, as indicated in Figure 2-2, is in fact a bird refuge. It has been designated as the Honouliuli Unit of the Pearl Harbor National Wildlife Refuge. Four endangered species of waterfowl are found on Oahu. The habitat of the *koloa* Hawai'i duck (*Anas whyillian*), Hawai'i gallinule (*Gallinula chloropus sandvicensis*), Hawaiian coot (*Fulica americana alai*) and Hawaiian stilt (*himantopus himantopus knudseni*) are expected to benefit from this project because they feed and breed in freshwater.

CULTURAL RESOURCES LAW

The National Historic Preservation Act (NHPA, 16 USC §470 et seq.) requires federal agencies to:

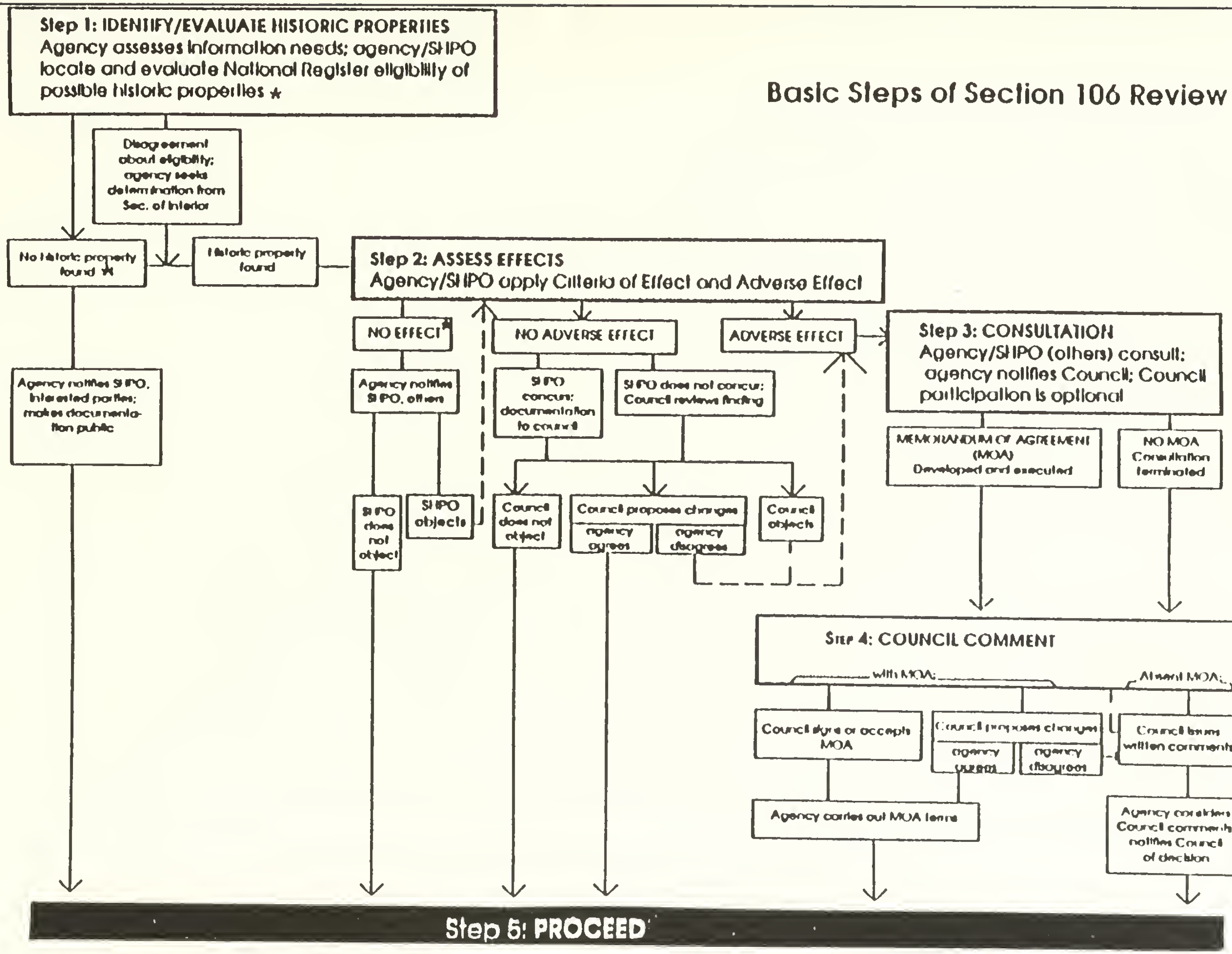
> administer historical properties in a spirit of stewardship;...and to take into account effects of federal undertakings on properties listed... on the National register of historic Places <u>before acting</u> (emphasis added) to minimize the undertaking's effects on national landmarks

"Undertakings" is broadly defined in 36 CFR 800.2(o) to mean anything funded with federal money. "Affect" is determined through a complicated process of consultation (Figure 2-3) defined in 36 CFR 800.3 and commonly known as Section 106 Review. Agency coordination with the State historic Preservation Office (SHPO) is not a waiver of Sovereign Immunity granted in the NHPA but rather a procedural requirement established by the Advisory Council of historic Preservation (ACHP) in 36 CFR 60 to speed the consultation requirements of §470(e). The Okiokilepe Fish Pond is the only officially recognized historic Site within NAVMAG (See Figure 2-2), but it is located



Source: (PACDIV,1989)

FIGURE 2-2 DEVELOPMENT CONSTRAINTS



Source: (PACDIV, 1992)

FIGURE 2-3

outside the proposed impoundment and would be unaffected (PACDIV, 1989). However, the entire facility lies within the boundaries of the Pearl Harbor National historic Landmark (PACDIV, 1984). Previous consultation has resulted in a Memorandum of Understanding with the ACHP and the SHPO that limits 106 Review requirements for most of the over 1000 facilities within this historic area.[8] Depending on final siting, review will probably not be required for this project if these considerations are properly documented in the Final EIS. If even the slightest potential exists for historic effect, the procedure should be conducted to avoid costly project delays[9]. The Archeological Resources Protection Act (ARPA, 16 USC §470aa) is an issue in this undertaking because fish ponds in the area are of cultural significance to Hawai'ians and local archaeologists (Tummons, 1991). This law prohibits the excavation, removal, damage, alteration or defacement of any archeological resource on federal property without first obtaining a permit. Strict criminal and civil penalties are established in §470ee(d) to enforce this statute. Should any human remains or burial artifacts be unearthed during excavation, §3005 of the Native American Graves Protection And Repatriation Act (25 USC 3001 et seq.) requires consultation with the Office of Hawaiian Affairs and Hui Malama I Na Kupuna O Hawai'i Nei to determine appropriate disposition of the cultural items.

CLEAN WATER ACT (Federal Water Pollution Control Act)
33 USCA §§1251 et seq.

The Federal Water Pollution Control Act and its subsequent amendments have dictated sweeping changes in the way our navigable waters are used to assimilate wastes. These legislative actions, collectively referred to as the Clean Water Act

[8] Memorandum of Understanding between Western Division of Project Review, ACHP and PACDIV of September 6, 1978.

[9] *Attaki v. United States*, 746 F. Supp. 1395 (D. Ariz. 1990) enjoined the government to halt a federal conservation and restoration project on Hopi Partitioned Lands until proper consultation was completed

(CWA), have already resulted in visible improvements to the water quality of the Pearl Harbor estuary. §1251 declares several congressional policy goals that are pertinent to this project:

(a) Restoration and maintenance of chemical, physical and biological integrity of the Nation's waters;
 (1) it is the national goal that discharge of pollutants into navigable waters be eliminated;
 (2) an interim goal is protection and propagation of fish, shellfish and wild life and provides for recreation in and on the water;
 (3) discharge of toxic pollutants in toxic amounts is prohibited;
 (5) areawide waste treatment management planning are implemented to assure adequate control of sources of pollutants in each State;
 (6) major research and demonstration effort be made to develop technology necessary to eliminate the discharge of pollutants; and
 (7) programs for the control of non-point sources of pollution be developed and implemented

(b) Congressional recognition, preservation and protection of primary responsibilities and rights of States

(g) Authority of States over water

§ 4334 and EO 12088 establish the responsibility of Federal agencies to support these goals[10]. A review of progress made to achieve each goal and objective within Pearl Harbor and its relationship to this freshwater impoundment project follows.

Elimination of Discharges

The latest comprehensive water quality study (Morris et al, 1973) indicated that high turbidity and low dissolved oxygen levels near the bottom have resulted primarily from agricultural practices and urban-industrial development. § 1281(g) of the CWA provided funding for the construction of the Honouliuli Waste Water Treatment Plant. This facility eliminated most of the 100 point sources which previously degraded water quality (PACDIV, 1990). Discharges of tail gate irrigation water from Oahu Sugar have been eliminated by recycling (Waite, 1991 and PACDIV, 1990). The cumulative effect of these actions is expected to result in improved water quality throughout the estuary. While a freshwater impoundment would not specifically eliminate any point

[10] EO 12088 of October 13, 1978; 43 FR 47707; 3 CFR (1978) p. 243. Section 1-101. The head of each Executive agency is responsible for ensuring that all necessary actions are taken for the prevention, control, and abatement of environmental pollution with response to Federal facilities.

discharges it would serve to control the distribution of nonpoint source pollutants from runoff of Waikele, Kipapa, Waikakalaua, and Honouliuli Streams.

Interim "Fishable and Swimmable" Goal

Subchapter III of the CWA established a system of Water quality standards and enforcement procedures to achieve the interim goals of §1251(a)(2). Congress directed the EPA to consult with State and Federal agencies to develop water quality criteria in § 1314(a)(1). These criteria provide continuity between the water pollution control programs of each State. Efforts to develop water quality criteria began in 1968 when the Federal Water Pollution Control Administration published the "Green Book". This publication provided much of the data for the first comprehensive criteria document, the "Blue Book" (Water Quality Criteria, 1972). Periodic updates have been provided by the "Red Book" (Quality Criteria for Water, 1976), and the "Yellow Book" (Quality Criteria for Water, 1986). Sedimentation has been identified as the predominant cause of pollution within Pearl Harbor (PACDIV, 1990).

Existing oyster populations within West Loch are already unfit for human consumption because of past pollution. These crustacea would not survive in the freshwater impoundment but containment of sediment within the impoundment would prevent future contamination of new oyster beds that could flourish below the dam.

Prohibit Discharge of Toxic Pollutants

Heavy metals are identified as the principal industrial pollutants in sediment throughout Pearl Harbor. These heavy metals are included on the toxic pollutant list mandated by § 1317(a)(1) and published in 40 CFR 401.15. Unfortunately many of the sources for these toxic pollutants are non-point, and therefore are not controlled by the effluent standards established in § 1317(a)(2) and 40 CFR 129. Demonstration projects are currently in progress to establish more appropriate standards for

contaminated pollutants.[11] In the absence of applicable non-point standards, the "Yellow Book" criteria for freshwater aquatic life or domestic water supply could be applied to evaluate the need for clean-up. If heavy metals levels are excessive, remediation might be achieved by dredging and disposal within an impermeable containment.[12] This could be accomplished by using these dredged spoils to construct the dam that creates the impoundment.

Areawide Waste Treatment Management Planning

§ 1288 established an areawide waste treatment management program that mandated:

> (a) Identification and designation of areas having substantial water quality control problems;
> (b)(1)(A) [Implementation of] a continuing areawide waste treatment management planning process consistent with section 1281 [that]:
>> (c) provide[s] control or treatment of all point and nonpoint sources of pollution, including in place or accumulated pollution sources.[13]

Support for water quality improvements in Pearl Harbor was originally galvanized by an EPA sponsored conference in September of 1971 (Stein, 1971). Progress on implementation of recommendations from this conference was reported in June of 1972 (Stein, 1972). Recommendations from this conference were incorporated into the State's formal Water Quality Management Plan (DOH, 1979). Several policies have been established to support the objectives of this plan that advocate an impoundment project (DLNR, 1984).

> <u>D. OBJECTIVE: Assure adequate municipal water supplies for planned urban growth.</u>
> In some areas, water use is approaching or has reached the available supply. Such areas as Pearl Harbor, have already been designated for regulation under the State Ground Water Use Act.[14]
> D(1)(a) IMPLEMENTING ACTION. Expand State exploration for new sources of surface... water supplies, with emphasis on areas experiencing critical water problems.

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[11] See *infra* note 14.
[12] See *infra* discussion of COE Permits which control this activity.
[13] While significant progress has been achieved in the control of point sources, much remains to be accomplished to control accumulated pollution. Regular channel dredging has reduced accumulated heavy metal concentrations in sediment (NEESA, 1983).
[14] Chapter 177, Hawaii Revised Statutes

D(1)(b) IMPLEMENTING ACTION. [C]onsider alternative means of increasing water supplies, such as blending brackish water with freshwater, desalting brackish water or seawater, and substituting lower quality water for potable water now used for non-domestic purposes...
E. OBJECTIVE. Assure availability of adequate water for agriculture.
E(1) POLICY. Preserve water for existing beneficial agricultural uses and provide additional water where needed by furthering development of existing surface...sources.
H. OBJECTIVE. Improve State grant and loan procedures for water programs and projects.
H(1)(a) [G]ive priority consideration to those municipal water projects and systems designed to service existing and planned urban area..., or designed to accommodate agricultural uses as well as domestic uses.

The Water Use Management Plan for the Pearl Harbor Ground Water Control Area[15] (PHGWCA) establishes policy for ground water use within the Pearl harbor aquifer:

POLICY 10: Encourage the development of alternative sources of water supply, including the importation of supplies from sources outside of the...PHGWCA, the reuse of supplies, the reclamation of waste water, particularly effluent from sewage treatment plants, the blending of brackish with freshwater to stretch the supply, and the desalting of brackish water.

Each user is also required to submit a plan which must include the essential elements specified in the Circular. The US Army, US Navy and Oahu Sugar Company and "Other Private Entities" are all required to develop Water Use Plans that include:

Current sources of supply other than ground water sources, and proposals... to develop exchange of non-potable... for potable water now used, the blending of fresh with brackish, or of supply through the use of imported water, the development of surface sources within the PHGWCA,... or the desalting of brackish water.

Research and Demonstration to Eliminate Discharge

Most of the research that has been conducted in support of the CWA goals has been directed toward point source problems. The construction of a freshwater impoundment could provide an ideal demonstration project for new and innovative methods of controlling accumulated pollution from non-point sources. § 1252, could provide a source of significant funding for this project:

(b) Planning for reservoirs; storage for regulation of streamflow
(3) The need for, the value of, and the impact of, storage for water quality control shall be determined by the [EPA]
(5) ...if the benefits [of impoundment] are widespread or national in scope, the costs of such features shall be nonreimbursable

[15] Department of Land and Natural Resources, Circular C-101

Non-Point Source Programs

After twenty years, the non-point source reduction programs mandated by § 1329 are still in infancy compared with the maturity of point source elimination methods. Ironically, after the expenditures of billions of dollars on effluent controls for point sources that cause less than ten percent of pollution problems (Liu, 1992), it is now clear that the "fishable and swimmable" goals of the CWA cannot be achieved without non-point source control (Freeman, 1990). The Water Quality Act of 1987[16] placed renewed emphasis on non-point source programs. Growing Congressional interest in removal of contaminated sediments[17] is manifested by the Great Lakes Critical Program Act[18] which amended §1268 to promote programs to:

> implement best management practices to reduce nutrient runoff and,
>
> conduct demonstration projects to control and remove toxic pollutants from bottom sediments.

This perspective on water pollution control could increase Congressional interest in an impoundment project and improve eligibility for limited funding from the grant program established in § 1281(g)(1)(B):

> (1) The Administrator is authorized to make grants to any State...on and after October 1, 1984, for: (B) any purpose for which a grant may be made under sections 1329:
>
> (h)(1) Grants for implementation of [non-point] management programs...[may use] funds reserved pursuant to section 1285(j)(5), Nonpoint source reservation:
>
> ...for each State 1 percent of the sums allotted... or $100,000, whichever is greater

[16] PL100-4, Title V, § 506, 101 Stats. 76

[17] CRS Bill Digest, 101st Congress, Vol. 1, 1989. Senate Bills S-1178 (p.A-232), S-1179 (p. A-234), S- 1210 (p. A-243) all attempted to address this issue. The transcript of the House of Representatives hearing No. 101-84, (CIS H561-44.1) of March 20, 1990 demonstrates the serious concerns of several Congressmen. The testimony of numerous technical experts and EPA staff provides a consensus opinion that this problem deserves attention now.

[18] Public Law 101-596, Title I, of November 16,1990. 104 Stat. 3000.

Primary Responsibilities and Rights of States

The FWPCA of 1972 reflects the frustration of Congress with the failure of individual States to successfully control pollution with water quality-based standards (Anderson, et al, 1990). But it also demonstrates the realization that such a comprehensive program could not and should not be administered from the Federal level. Consequently §1251(b) sets the ground rules for State implementation of Federal water pollution policy. Pursuant to § 1313 the State of Hawai'i has codified water quality standards in Title 11, Chapter 54 of the Hawai'i Administrative Rules. §11-54-05(b)(3) identifies Pearl Harbor as a Class 2, inland estuary. No new industrial discharges are permitted in Class 2 waters. Special standards (Figure 2-4) are listed for Pearl Harbor in §11-54-05(c)(4)(B). Water quality standards differ in freshwater impoundments. §11-54-05(c)(1) states:

> ... Only the basic criteria set forth in §11-54-04 apply to ...reservoirs

These standards were revised in January 1990 to establish numeric levels for toxic pollutants[19]. This provides the current legal basis to evaluate the impact of sediment laden with heavy metals on the surrounding water column.

State Allocation of Water Rights

Water rights have been hotly contested since the days of the monarchy. According to the State Constitution:

> The State has an obligation to protect, control and regulate the use of Hawaii's water resources for the benefit of its people.

The development of a State Water Code[20] has evolved over the past 15 years to compromise the interests of both riparian and appropriation doctrine with ancient

[19] Hawaii Administrative Rules Title 11, Chap. 11, § 04 (b)(3)
[20] Chapter 174C, Hawaii Revised Statutes

STATE OF HAWAII WATER QUALITY STANDARDS
APPLICABLE TO PEARL HARBOR

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value
Total Kjeldahl Nitrogen (ug N/1)	300.00	550.00	750.00
Ammonia Nitrogen (u/g NH_4-N/1)	10.00	20.00	30.00
Nitrate + Nitrate Nitrogen (ug[NO_3 +NO_2]-N/1)	15.00	40.00	70.00
Orthophosphate Phosphorus (ug PO_4-P/1)	20.00	48.00	90.00
Light Extinction Coefficient (k units)	0.80	1.60	2.50
Chlorophyll a (ug/1)	3.50	10.00	20.00
Turbidity (Nephelometric Turbidity Units)	4.00	8.00	15.00
Non-filtrable Residue (us/1)	50,000.00	75,000.00	100,000.00

Notes:

pH units shall not deviate more than 0.5 units from ambient conditions and shall not be lower than 6.8 nor higher than 8.8.

Dissolved Oxygen - Not less than 60% saturation.

Temperature - Shall not vary more than 1° C from ambient conditions.

Salinity (ppm) - Shall not vary more than 10% from ambient conditions.

Oxidation - Reduction potential (E_H) in the uppermost 10 cm. (4 inches) of sediment shall not be less than -100 mv.

FIGURE 2-4

Hawaiian "konohiki" rights. The result is a system that seeks to accommodate user requirements while maintaining sustainable yields. This is accomplished by granting permits in perpetuity which are reviewed every twenty years to ensure the following conditions of use are satisfied:

> § 174C-49(1) can be accommodated with the available water source;
> (2) Is a reasonable-beneficial use as defined in § 174C-3;
> (3) Will not interfere with any existing legal use of water;
> (4) Is consistent with the public interest;
> (5) Is consistent with state and county general plans and land use designations;
> (6) Is consistent with county land use plans and policies;
> (7) Will not interfere with the rights of the department of Hawaiian home lands...

The success of this approach relies on the willingness of users within over-allocated areas such as the PHGWCA, to invest in source development and conservation instead of high risk, costly battles.[21] The rapid growth in the Ewa Plain has created a greater demand for water than existing allocations can support (Dooley, 1988 and Tillis, 1989). The motivation for State, City and County of Honolulu and private developers to cooperate in a joint venture for water resources development is apparent. In addition to reaffirming the States authority to allocate water within its boundaries, § 1251 (g) provides the most compelling motive for this project by instructing Federal agencies to:

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[21] The State Water Code uses much of the case law in formulating its regulations but has rejected some court opinions. See: (1) §174C-49(c) The common law of the State not withstanding...
(2) *Reppun v. Board of Water Supply*, 65 Hawaii 531 (1982);
(3) *McBryde Sugar Co. v. Robinson*, 54 Hawaii 174, 504; P.2d 1330 (1973), *cert. denied*;
417 US 976 (1974), *cert. denied and appeal dismissed sub. nom.*
(4) *McBryde Sugar Co. v. Hawaii, 4717 US 962 (1974)*
(5) *City Mill v. Honolulu Sewer and Water Commission*, 30 Hawaii 912 (1929)
(6) *Robinson v. Ariyoshi*, 65 Hawaii 641, 667 (1982)
For an in depth review of water rights doctrine and the impact of case law on a State Water Code see:
Chang W.B.C. February 1987. Water Code Development in Hawaii: History and Analysis, 1978-1987, Technical Report. No. 173. Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii.
Chang, W.B.C. and Moncur, J.E.T. September 1984. Reppun v. BWS: Property Rights, Economic Efficiency and Ensuring Minimum Sreamflow Standards, Technical Report. No. 165. Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii.
Kloss, W., Aipa, N., Chang, W.B.C. May 1983. Water rights, Water Regulation, and the "Taking Issue" in Hawaii, Technical Report. No. 150. Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii.

cooperate with State and local agencies to develop comprehensive solutions to prevent, reduce and eliminate pollution in concert with programs for managing water resources. (emphasis added).

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT of 1980 (CERCLA), 42 USC §§ 9601 and SUPERFUND AMENDMENT AND REAUTHORIZATION ACT (SARA)[22]

CERCLA and the SARA amendments establish a hazard ranking system[23] that is used to prioritize the sites of known hazardous waste releases throughout the United States.[24] Funds are made available from the Superfund[25] to sites included on this National Priority List.(NPL)[26]. §9611(e)(3) restricts the use of the Superfund on federally owned facilities except for § 9611(c)(1) costs incurred for:

> ...assessing both the short-term and long-term injury to, destruction of or loss of any natural resources resulting from the release of hazardous substance.

However, this does not relieve Federal agencies of responsibility for cleaning up known releases.[27] The Defense Environmental Restoration Program was established by 10 CFR 2701 to ensure:

> (a)(2) Activities of the program... shall be carried out... in a manner consistent with, section 120 of CERCLA.
> (b) Goals of the program shall include the following:
> > (1) Identification, investigation, research and development, and cleanup of contamination from hazardous substances, pollutants, and contaminants.
> > (2) Correction of other environmental damage which creates an imminent and substantial endangerment to the public health or welfare or to the environment.

The Navy's Initial Assessment of sediment contamination within Pearl Harbor (NEESA, 1983) indicated much of the contaminated sediments in the harbor and channels has already been removed by maintenance dredging. Since all likely impoundment sites lie outside of the previously dredged areas and in light of the

[22] October 17, 1986. PL 99-499.
[23] 42 CFR 9605(c)
[24] 42 CFR 9605(a)(8)(B)
[25] Established under Subchapter A of Chapter 98 of Title 26.
[26] 42 CFR 9611(a)(2)
[27] 42 CFR 9620

potential use as a potable water source, further evaluation for remediation will be undertake in Chapter Three.

CORP OF ENGINEER PERMITS

The Corp of Engineers (COE) is granted authority to issue applicable permits under three statutes. Two definitely must be obtained to proceed with impoundment and the third may be required depending on the final method of construction. § 9 of the Rivers and Harbors Act[28]prohibits:

> the construction of any dam or dike across any navigable water of the United States in the absence of Congressional consent and the approval of the plans by the Chief of Engineers.

The CWA[29] tasks the COE with issuing "Section 404" permits for dredged and fill material using guidelines established by the EPA. 40 CFR 232 provides a list of exempted activities but no exclusion is appropriate for this impoundment project. 33 CFR 323 lists the permit requirements for disposal at specified dump sites while 33 CFR 325 describes the consolidated procedures that simplify compliance with both § 404 and the Coastal Zone Management Act of 1972.[30] Although 40 CFR 401.11(f) defines pollutant to include "any dredged spoil", § 122.3(b) excludes any discharge of dredged or fill material from National Pollution Discharge Elimination System (NPDES) permitting[31] if they are covered by a 404 Permit.

A third COE permit is required if dredged spoils are to be disposed at sea. The Marine Protection, Research, and Sanctuaries Act[32] grants the COE authority to issue permits for ocean dumping of dredged material. The EPA sets the conditions for these permits in 40 CFR 220-229. § 233.3(a) specifically states:

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[28] 33 USC 401 of March 3, 1899

[29] 33 CFR 1344. EPA still retains the authority to overule a COE issued 404 permit per 40 CFR 227

[30] 16 USCA § 1451-1464

[31] See 40 CFR 122

[32] 33 USCA § 1413 & 1414

> If any discharge of dredged or fill material... contains a toxic pollutant listed under § 307(a)(1)...[it] shall be subject to any applicable toxic effluent standard...and require a § 404 permit

Since effluent limits have only been published for six toxics[33] the EPA relys on a process of bioassay to determine the direct effect of other toxics on marine biota prevalent at the disposal site[34].

SAFE DRINKING WATER ACT (Public Health Service Act. Title XIV) 42 USCA §§ 300f-300j-26

Resolution of groundwater shortfalls within the PHGWCA have focused on reallocation of non-potable sources to replace potable supplies that are currently used for irrigation. This would free significant amounts of groundwater for potable use at developments in the Ewa Plain. Sugar and pineapple growers have invested significant sums of money to develop these groundwater sources. Legal challenges to the State Water Code by these agricultural interests, which have well established water rights, would be likely. To avoid this divisive situation the economy of using impounded surface water as a new potable supply should be considered. The Safe Drinking Water Act (SDWA) establishes national primary drinking water standards (NPDWS) that specify maximum contaminant levels (MCL). These MCLs, listed in 40 CFR 141, indicate the water quality that must be attained at the tap. The director of the Department of Health has authority to issue more stringent regulations,[35] but the State has adopted the SDWA primary standards.[36]

§ 141.5(a) establishes some siting requirements that may limit or preclude construction of this project.

> Before a person may...initiate construction of a new ..public water system ... he shall... avoid locating ... the new ... facility at a site which:

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[33] 40 CFR 401.15
[34] 40 CFR 129
[35] Hawaii Revised Statutes, Title 19, Chapter 340E-3
[36] Hawaii Revised Statutes, Title 19, Chapter 340E-2(a)

> (a) Is subject to significant risk from ... disasters which could cause a breakdown of the public water system or portion thereof; or
> (b) ...is within the floodplain of a 100-year flood or is lower than any recorded high tide.

Since this project would lie within the explosive safety (ESQD) arc of the NAVMAG an early assessment of potential damage to the dam structure must be conducted by the State and the US Navy.

The "surface water treatment rule" (SWTR) is established by § 141.73. It requires that public water systems using surface sources that do not satisfy exemption criteria:[37]

> must provide treatment consisting of both disinfection ... and filtration...

§ 141.74 places extensive monitoring requirements on the public utility to ensure that treatment methods satisfy the NPDWS. The use of impounded freshwater as a potable supply will definitely require both of these basic treatment methods. Additional treatment methods may be necessary to achieve the primary and secondary standards established by the SDWA as well as the water quality goals that have been adopted by the American Water Works Association (Davis, 1991).

SUMMARY

While the magnitude of the numerous legal considerations may seem overwhelming they do provide a useful road map to evaluate the viability of impoundment as solution to impending water shortfalls. Environmental legislation may also provide the only available funding source for a project of this magnitude during the current austere financial climate. The key to meeting the challenge of expanding water supply to satisfy future demand lies in a synergistic approach which garners the benefits of environmental restoration with conservation of natural resources. Opportunities do exist to accomplish this goal in concert with essential growth in both

[37] 40 CFR141.71(a) & (b)

private and public sectors, if all affected parties seek ways to achieve mutual benefits. In Chapter Three we will investigate existing water and sediment quality in both Waikele Stream and West Loch to determine specific actions that are appropriate under these laws.

REFERENCES

Chief of Naval Operations (CNO), May 2, 1986. Environmental and Natural Resources Protection Manual, OPNAVINST 5090.2

Department of Health (DOH), 1979 "*Water Quality Management Plan for the City and County of Honolulu*", State of Hawai'i

Department of Land and Natural Resources (DLNR), June 1984. "*Water Management Plan for the Pearl Harbor Ground Water Control Area*". State of Hawai'i

Dooley, J. 16 October 1989. "Ewa water could be gold Haseko's money can't buy", Honolulu Advertiser, Honolulu, Hawai'i.

Freeman, A.M., 1990. "*Water Pollution Policy*", Public Policies for Environmental Protection, P.R. Portney, editor. Resources for the Future, Washington, D.C.

Liu, Ed, March 19, 1992. "Clean Water Act Water Quality Management and Monitoring in the 1990s". EPA Region IX, Water Management Division, Monitoring Coordinator. Water Resources Research Center Seminar, University of Hawai'i Manoa, Honolulu, Hawai'i.

Morris, D.E., Surface, S.W., and Murray, J.P., 1973. *Navy Environmental Protection Data Base: Completion Report for the Pearl Harbor, Hawai'i Study Covering the Test Period through Calendar Year 1972.* Naval Civil Engineering Laboratory, Port Hueneme, California

Naval Energy and Environmental Support Activity (NEESA), October 1983. "*Initial Assessment Study of Pearl Harbor Naval Base, Oahu, Hawai'i*". NEESA Report 13-002. US Navy, Port. Hueneme, California

Pacific Division Naval Facilities Engineering Command (PACDIV), 06 February 1984. "*Pearl Harbor Naval Complex - Master Plan.*", Oahu Hawai'i.

PACDIV, 18 December 1989. "*Revision 1 to Master Plan for Naval Magazine Lualualei*", Oahu Hawai'i.

PACDIV, August 1990. "*Final Environmental Impact Statement for Proposed Developments At Naval Base Pearl Harbor, Oahu Hawai'i.*"

PACDIV, 1992. *"Environmental Law for Non-Lawyers"*. Study Guide for Short course given by the Naval Facilities Engineering Command. Pearl Harbor, Hawai'i.

Stein, M., October 21-22, 1971. *"PROCEEDINGS: In the Matter of Pollution of the Navigable Waters of Pearl Harbor and its Tributaries-Hawai'i"*. Transcript of Proceedings

Stein, M,, June 5-6, 1972. *"TECHNICAL SESSION: In the Matter of Pollution of the Navigable Waters of Pearl Harbor and its Tributaries-Hawai'i"*. Transcript of Proceedings

Teas, H. J., 01 March 1988. "Evaluation of A Plan for Diversion of Waikele Stream Water for Irrigation by Use of Membrane Structures
Appendix I, Draft Technical Report. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Teas, H. J., 01 March 1988. "Evaluation of A Plan for Impoundment of Freshwater in West Loch for Irrigation "Appendix II, Draft Technical Report. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Tillis, V. July 1988. "Second City: Already Under Way on West Oahu Plain", Building Industry Digest, Vol. 34, No. 3, Honolulu, Hawai'i.

Tummons, P. December 1991. Environment Hawai'i, Vol. 2, No. 6. Honolulu, Hawai'i.

Work, S.W., Miller, W.H., Pokorney, E.E., June 18-22, 1989. "Reservoirs- The Endangered Species". 1989 Annual Conference Proceedings, American Water Works Association, Los Angeles, California.

CHAPTER THREE

Assessment of Current Water Quality

Concerns about poor water quality within the Pearl Harbor Estuary have caused previous researchers to dismiss the possibility of using impounded surface water for potable use. The potential for potable use depends on the quality of the source of freshwater and how the water quality may be effected by the residual pollutants in the sediment of West Loch. The Federal Water Pollution Control Act and the many amendments which are now commonly referred to as the Clean Water Act (CWA), are believed to have resulted in substantial improvements. This premise suggests reconsideration of the possible uses for a fresh surface water impoundment.

The first step in this process is the identification of data that can quantify the purported water quality improvements or identify contamination levels. Deteriorating water quality first generated public attention in 1969 when the Federal Water Pollution Control Administration issued a "Report on Pollution of the Waters of Pearl Harbor" (FWPCA, 1969). This report identified untreated waste discharges from Federal, municipal, and industrial sources responsible for adverse effects on the natural resources in the harbor. Coliform bacterial contamination of oysters in West Loch presented a hazard to health and sedimentation jeopardized the existence of oyster populations Concern grew with increasing events of "red tide" and the proliferation of offense odors. These events stimulated a series of public meetings (Stein, 1971 and 1972) which perpetuated the action of the Pearl Harbor Task Force. This group coordinated the abatement actions of all levels of government and affected industries in the (PACDIV, 1971 and Commandant Fourteenth Naval District, 1977). As the custodian of the public lands which compose the Pearl Harbor Naval Complex, the US Navy conducted an extensive water quality and sediment study to quantify these conditions (Morris, et al, 1972). This study established a baseline to measure the

effectiveness of pollution control abatement actions and recommended the continuation of monthly and quarterly testing at seventeen sampling stations. Expense and a subsequent study that questioned the effectiveness of chemical testing to evaluate environmental quality (Naval Undersea Center, 1974), resulted in the adoption of selective environmental monitoring at only critical locations on a continuous basis. A significant amount of additional test data is available as a result of specific projects conducted during the past twenty years. Perhaps the most useful data has been compiled to support dredging throughout the harbor. A recent evaluation of all available data indicates "measurable patterns of improving environmental quality" (Grovhoug, 1992). Only one other useful water quality study (DOH, 1991) was revealed during a thorough literature search. Considerable evidence of substantial water quality testing by the City and County of Honolulu exists but most of this data has been destroyed as a result of administrative procedures which dictate retention for only three years.

Waikele Stream is the predominant source of surface water for impoundment. Water Quality data is readily available for more than eighty parameters from US Geological Survey (USGS) stream gauging station number 16213000 (USGS, 1981).

APPLICABLE WATER QUALITY STANDARDS

The State of Hawaii's water quality standards were enumerated in Chapter Two (see Figure 2-4). The special standards established for Pearl Harbor would not be applicable to the impounded portion of West Loch because it would contain freshwater. Within the reservoir , the numeric levels of §11-54-04(b)(3) provides the current basis to evaluate the impact of sediment laden with heavy metals, on the surrounding water column.

The Safe Drinking Water Act (SDWA)[38] establishes national primary drinking water standards that specify maximum contaminant levels (MCL). These MCLs, listed in 40 CFR 141, indicate the water quality that must be attained at the tap. The State has adopted these primary standards and they provide the basis for determining mandatory levels of treatment. Secondary (SMCL) drinking water standards, maximum contaminant level goals (MCLG), and the American Water Works Association water quality goals provide additional targets that are more stringent but do not require mandatory compliance. For the purposes of this study the strictest standard will be applied.

WATER QUALITY of WAIKELE STREAM

While not totally comprehensive, the USGS data provides a good indication of water quality parameters which will require treatment. As a first step this data was compared to SDWA standards and twenty-nine parameters were analyzed in detail to determine those that might require surface water treatment. The graphs in Appendix A depict the maximum and minimum observed values, as well as the calculated geometric mean for each year since 1973.

Turbidity (A-117), Lead (A-133), Manganese (A-134), Fecal Coliform (A-139) and Total Dissolved Solids (A-142) all violate drinking water standards a significant portion of the study period. Additionally, observed levels of Hardness (A-124), Chlorides (A-125), Iron (A-132), and Aluminum (A-137) are high enough to warrant further evaluation. It has been speculated that coliform counts and turbidity would increase after impoundment (Teas, 1988). The fate of each of these nine critical contaminants, in a freshwater impoundment, should be assessed before estimating ultimate treatment requirements. but comparison with average raw water concentrations from other municipal sources. Table 3-1 compares Waikele water with raw water

[38]Public Health Service Act. Title XIV, 42 USCA §§ 300f-300j-26

samples from the Missouri River tested by St. Louis municipal utilities prior to treatment (St. Louis County Water Company, 1991 and Visintainer, 1993) and EPA's limiting raw water criteria (Gumerman, 1979).

Table 3-1. Comparison of Average Raw Water Quality

Parameter	Units	Waikele Stream	Missouri River	EPA Maximum
COLIFORM	**col/100ml**	**6136**	**22,600**	**<20,000**
TURBIDITY	**NTU**	**6.25**	**412**	**>1000**
TDS	**mg/l**	**227**	**369**	**No Standard**
MANGANESE	**ug/l**	**52.41**	**4.5**	**No Limit**
LEAD	**ug/l**	**3**	**<1**	**1700**
HARDNESS	**mg/l**	**57.76**	**200**	**No Standard**
IRON	**ug/l**	**50.83**	**39.1**	**No Standard**
ALUMINUM	**ug/l**	**19.95**	**27**	**No Standard**
CHLORIDES	**mg/l**	**61.14**	**18.4**	**No Standard**

Both the City and County of St. Louis have reputations for producing consistently high quality potable water using conventional treatment techniques. This comparison demonstrates that Waikele Stream can provide an excellent source for potable treatment since concentrations of all but three critical water quality parameters are far below those of current municipal raw water sources. The remaining three parameters fall well within the range of acceptable raw water

Data for synthetic organic chemicals (SOC) and volatile organic chemicals (VOC) are conspicuously absent. Unfortunately these contaminants are expensive to detect and consequently are not regularly monitored at the Waikele station. Based on the low levels of these pollutants observed in recent Pearl Harbor data (AECOS, 1986, 1989 &1990) it seems prudent at this stage of planning to assume that no treatment will be necessary to remove SOC or VOC. A confirmation study should be conducted if further planning is warranted.

WATER QUALITY of PEARL HARBOR

Water quality data within the Pearl Harbor estuary and more specifically for West Loch, lacks the consistency of the Waikele data. However, much can be inferred from the available information. The baseline study linked high turbidity and low dissolved oxygen levels near the bottom of West Loch, to agricultural and urban runoff. high nutrient and coliform levels corresponded closely to source discharges of raw sewage or highly concentrated effluent from oxidation ponds. All of the specific sources identified have subsequently been eliminated by abatement efforts. However, the State standards for coliform levels[39] are still consistently violated as a direct result of non-point source pollution (DoH, 1990). Consequently the entire estuary is designated as a Water-Quality Limited Segment (WQLS). This indicates that is unlikely that standards can be achieved without control of non-point sources.

Heavy metals in the water column of West Loch can be correlated predominately to ambient soil conditions rather than industrial pollution. Less than 5% of the 7281 metal analyses conducted during the baseline study detected dissolved metals. Mercury was the only toxic inorganic substance detected but it did not exceed the MCL (A-143). Iron, Manganese, Magnesium, and Zinc were the most prevalent dissolved metals detected (Morris, Surface and Murray, 1973). The high detection limits used in these tests does cause some concern regarding the usefulness of this data. Field observations made during numerous studies over the past ten years, have consistently ranked the general environmental quality of West Loch higher than other areas of the estuary (Grovhoug, 1992). Unfortunately no comprehensive water quality data has been gathered from West Loch since the base-line study, to substantiate this opinion. For the purpose of this investigation, sediment contamination is the more pertinent issue because it could potentially affect the freshwater quality after

[39]Title 11, Chapter 54 of the Hawaii Administrative Rules. §11-54-08

impoundment whereas any contaminated saltwater would be pumped from the reservoir.

IMPACT of SEDIMENT CONTAMINATION on WATER QUALITY

Pearl Harbor has functioned as a natural sedimentation basin throughout geologic history. Sedimentation is the most significant remaining pollution problem within the estuary as almost 100,000 tons of material is discharged annually (Commandant Fourteenth Naval District, 1977). Figures 29 &30 illustrate the variability of this natural phenomenon in West Loch. The baseline sediment study indicates that cadmium, chromium, copper, lead, mercury, nickel and silver, and zinc have accumulated in harbor sediments from stream deposition and man-made sources. Correlation of these concentrations with the presence of dissolved metals in the water column was not convincing. It goes on to suggest a strong relationship between heavy metal concentrations and biological quality (Morris & Youngberg, 1972). Bioassays do not support this contention, however. In fact sediment from all areas of the estuary have consistently produced no negligible effects on test organism survivability (Grovhoug, 1992). Monitoring of the near shore dredge disposal site also indicate that "spoil material was low in metals and pesticides" (Environmental Center, 1977). A Navy pollution assessment team concluded that elimination of discharges and maintenance dredging of sediments had reduced contamination sufficiently enough to pose no threat to human health (NEESA, 1983). Contamination concentrations have shown a significant decrease throughout the estuary since 1972.

Table 3-2 compares concentrations in the upper reaches of West Loch with the Low Effects Range Concentration determined by the National Oceanic & Atmospheric Administration's (NOAA) National Status and Trends Program (O'Connor, 1990). It confirms that levels of sediment contamination in West Loch are below the lower 10th percentile. This indicates that Pearl Harbor is cleaner than most ports in the nation.

TABLE 3-2. SEDIMENT CONTAMINATION TRENDS

CONTAMINANT	LOW EFFECTS RANGE[a]	1972[b] mg/kg	1990[c] mg/kg
Cadmium(Cd)	5.0	0.47	0.4
Chromium(Cr)	80	120	35.4
Copper(Cu)	70	72	28.2
Lead(Hg)	35	20	15.5
Mercury(Pb)	0.15	0.31	0.15
Silver(Ag)	1.0	2.0	0.8
Zinc(Zn)	120	160	47.0
PCB(1260)	0.5	---	ND (<.15)
ΣOrganotin	NS	---	.025
ΣPetroleum Hydrocarbons	NS	---	ND(<50)
ΣPAH	4.0	---	ND(<1.0)
ΣChlordane	0.5	---	ND(<0.3)
ΣDDT			ND(<0.03)

NS- No Standard --- Not Tested

[a] O'Connor, T.P., 1990. *"Coastal environmental quality in the United States, 1990: chemical contamination in sediments and tissues"*. Represents the lower 10th percentiles in effects-based NOAA data

[b] Morris, D.E. and Youngberg, A.D., April 1972. *Methods of Collection and Reporting of Sediment Samples from Pearl Harbor.* and Evans, E.C., 30 August 1974. *"Pearl Harbor Biological Survey - Final Report"*

[c] AECOS, Inc., 1990. "Bioassay and bioaccumulation for Pearl Harbor dredged material disposal: laboratory results"

SUMMARY

1) High levels of coliforms, turbidity, total dissolved solids, manganese, and lead will probably require treatment if water from Waikele Stream is to be used for potable supply.

2) The above noted stream quality parameters, as well as hardness, iron, aluminum and chloride, should be evaluated to estimate their fate in a freshwater impoundment. An initial assessment of these parameters will be made in the next chapter.

3) The concentrations of stream quality parameters that violates SDWA standards are not too high to preclude effective treatment.

4) In spite of significant pollution abatement action, Pearl Harbor still exceeds State water quality standards

5) Substantial data is available to support claims of continuing water quality improvement. Resumption of limited sampling on a bi-monthly basis at the seventeen stations recommended in the baseline study, in conjunction with USGS stream quality monitoring, could provide valuable information to assess the impacts of non-point source pollutants.

6) Levels of sediment contamination within Pearl Harbor are lower than the low effects range established by NOAA and appears to have improved as a result of point source control and maintenance dredging. Therefore, it would not qualify for any remediation under either the Superfund or the DOD Installation Restoration Program.

7) Sediment contaminants do not adversely impact the quality of the water column and seem to have minimal impact on bioassay test organisms.

8) The fate of sediment contaminates should be evaluated to ensure that freshwater impoundment will not increase concentrations of toxic inorganic substances.

REFERENCES

AECOS, Inc., 15 April 1986. "Middle Loch Elutriate Test Results", Pearl Harbor, Hawai'i

AECOS, Inc., 01 March 1989. "Magazine Loch Elutriate Test Results", Pearl Harbor, Hawai'i

AECOS, Inc., 1990. "Bioassay and bioaccumulation for Pearl Harbor dredged material disposal: laboratory results" PACDIV, Pearl Harbor, Hawai'i

Commandant, Fourteenth Naval District, 13 October 1977. *"Proceedings of Navy Action '77, Environmental Conference on Erosion and Tributary Flow"*. Honolulu, Hawai'i

Department of Health (DOH), January 1990. *"Hawaii's Assessment of Non-point Source Pollution Water Quality Problems"*, State of Hawai'i

Department of Health (DOH), November 1991. *"Hawai'i Toxics Monitoring Program Background and Results of Toxics Metals Analyses, 1989 and 1990"*, Clean Water Branch, State of Hawai'i

Environmental Center, University of Hawai'i, May 19, 1978. *Baseline Studies and Evaluation of the Physical, Chemical, and Biological Characteristics of Nearshore Dredge Spoil Disposal, Pearl Harbor, Hawai'i.* Pacific Division Naval Facilities Engineering Command, Pearl Harbor, Hawai'i.

EPA, August 1971. *Addendum to Report on Pollution of the Navigable Waters of Pearl Harbor.*

Evans, E.C., 30 August 1974. *"Pearl Harbor Biological Survey - Final Report"* Hawai'i Laboratory, Naval Undersea Center, San Diego, California

Federal Water Pollution Control Administration, Pacific Southwest Division (FWPCA), October 1969. *Report on Pollution of the Navigable Waters of Pearl Harbor.* US. Department of the Interior.

Gumerman, R.C., Culp, R.L. and Hansen, S.P., August 1979. *"Estimating Water Treatment Costs"*. Environmental Protection Agency publication EPA-600/2-79-162 a&b.

Grovhoug, J.G., January 1992. *"Pearl Harbor Environmental Site Investigation: An Evaluation of Potential Sediment Contamination Effects"*. Marine Environmental Support Office, Hawai'i Lab, Naval Command, Control and Ocean Surveillance Center, Kailua Hawai'i

Morris, D.E., Surface, S.W., and Murray, J.P., 1973. *"Navy Environmental Protection Data Base: Completion Report for the Pearl Harbor, Hawai'i Study Covering the Test Period through Calendar Year 1972"*. Environmental Protection Data Base Office, Pearl Harbor Division, Naval Civil Engineering Laboratory, Port Hueneme, California

Morris, D.E. and Youngberg, A.D., April 1972. *Methods of Collection and Reporting of Sediment Samples from Pearl Harbor. EPDB 73-001*. Environmental Protection Data Base Office, Pearl Harbor Division, Naval Civil Engineering Laboratory, Port Hueneme, California

Naval Energy and Environmental Support Activity (NEESA), October 1983. *"Initial Assessment Study of Pearl Harbor Naval Base, Oahu, Hawai'i"*. NEESA Report 13-002. US Navy, Port. Hueneme, California

O'Connor, T.P., 1990. *"Coastal environmental quality in the United States, 1990: chemical contamination in sediments and tissues"*. A special NOAA 20th Anniversary Report, National Status and Trends Program, Coastal and Estuarine Assessments Branch

Pacific Division Naval Facilities Engineering Command (PACDIV), 06 February 1984. *Pearl Harbor Naval Complex - Master Plan."*

PACDIV, August 1990. *"Final Environmental Impact Statement for Proposed Developments At Naval Base Pearl Harbor"*, Oahu Hawai'i.

PACDIV and Commander, Naval Base , Pearl Harbor, August 1971, *Pollution Status and Control Report, Demonstration Program for Pearl Harbor Area, Oahu, Hawai'i.*

St. Louis County Water Company, 1991. *"Bacteriological Summary: Table 11-1"*. Annual Report, St. Louis, Missouri.

Stein, M., October 21-22, 1971. *"PROCEEDINGS: In the Matter of Pollution of the Navigable Waters of Pearl Harbor and its Tributaries-Hawai'i"*. Transcript of Proceedings

Stein, M,, June 5-6, 1972. *"TECHNICAL SESSION: In the Matter of Pollution of the Navigable Waters of Pearl Harbor and its Tributaries-Hawai'i"*. Transcript of Proceedings

Teas, H. J., 01 March 1988. *""Evaluation of A Plan for Impoundment of Freshwater in West Loch for Irrigation".* Appendix II, Draft Technical Report. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

United States Geological Survey (USGS), 1981. *"Summary of Available Data on Surface Water, State of Hawai'i, Volume 4".* Open-File Report 81-1056. US Department of Interior, Honolulu, Hawai'i.

Visintainer, D.A., January 14, 1993. *Request for Financial And Operating Data.* Official Letter, Water Division, Department of Public Utilities, City of St. Louis, MO

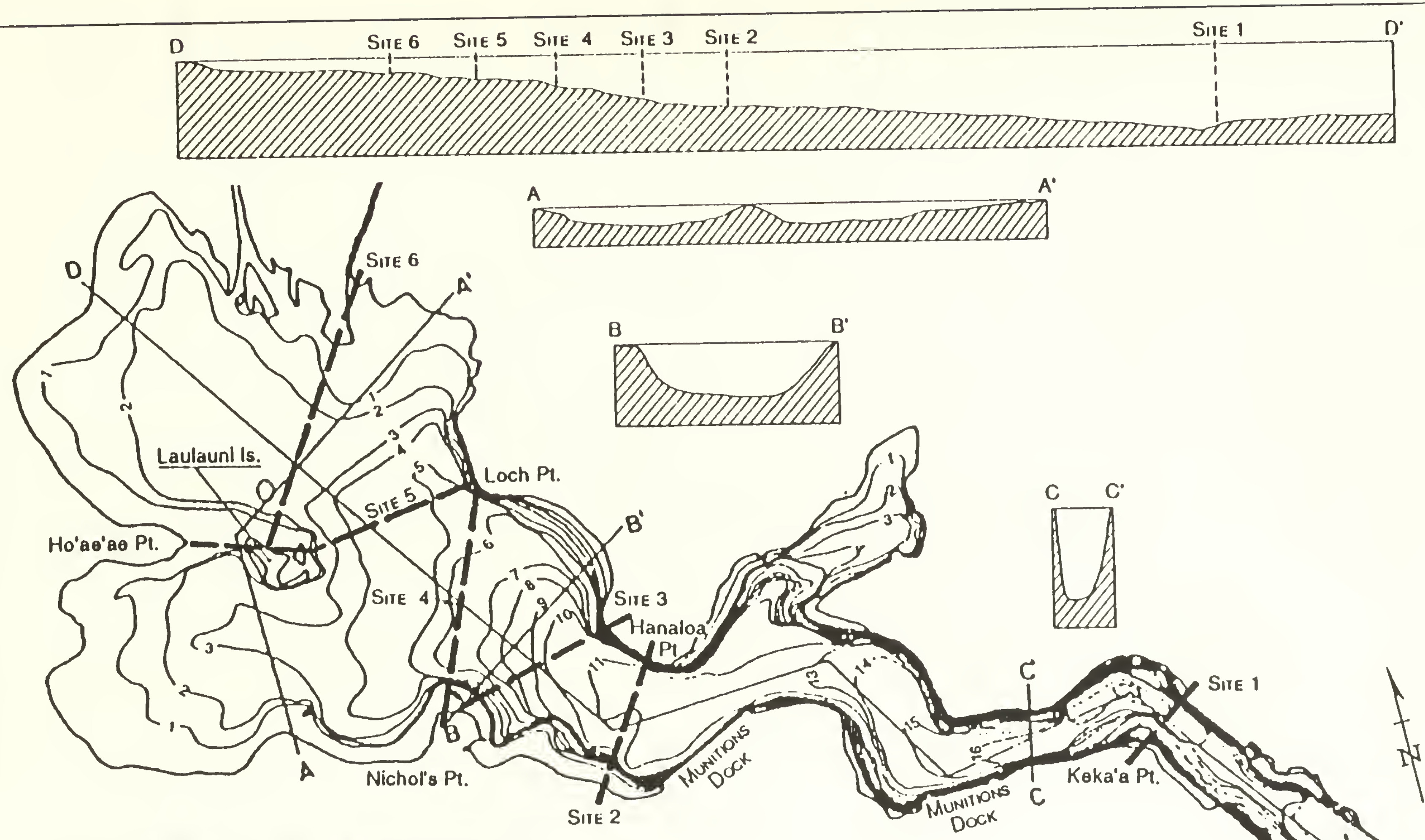
CHAPTER FOUR
Effects of Impoundment

In order to estimate the treatment requirements for surface water from the Waikele drainage basin, it is important to consider the effect that impoundment will have on the source water. "Concentrations of trace elements and their variations in raw water supplies are of prime importance in relation to the ultimate quality of the finished water reaching the consumer." (Andelman, 1975). Retention of surface water in a coastal reservoir will, without question, alter the quality of the inflows (Gower, 1980). Modeling of lakes and reservoirs is a complex task which requires evaluation of many factors. By the late 70s, over 90 working models for surface impoundments had been developed in more than 400 references. The usefulness of these models was usually limited by the availability of accurate data to adequately describe the interrelated parameters affecting the impoundment. (Orlob, 1983). Even simple single dimensional models that rely on several general assumptions to reduce the number of parameters, require reliable flow, temperature, and water quality concentration data for all tributaries.

The development of a model for the West Loch impoundment is an important part of the design process but is out of the scope of this planning assessment. A review of available data and application of general observations from other studies can give us a general approximation of the effect of impoundment on the nine critical parameters identified in Chapter Three.

IMPOUNDMENT CHARACTERISTICS

Six alternative dam sites have been proposed for the West Loch impoundment (Figure 4-1). Each offers unique benefits and drawbacks (Fok & Murabayashi, 1992).



Note: Contours based on government surveys to 1969 - N O Chart 19084, contour interval at one meter (1.094 yd). Profile vertical exaggeration at 1:25

Source: Adapted from (Turner, 1975
by (Fok & Murabayashi, 1992)

FIGURE 4-1

PROPOSED DAM SITES

Although the Navy has previously voiced some reservation, it appears that Site 3 can provide a reservoir of adequate storage capacity (Table 4-1) without interfering with the turning basin required for ships leaving wharves 1&2. This would require a dam of limited crossection to prevent the downstream shell from encroaching into the ship channel. The feasibility of such a design will be examined in the next chapter.

Table 4-1. Physical Characteristics of an Impoundment at Site 3.

Longitudinal Length	7800 feet (2377 meters)
Average Width	4557 feet (1388 meters)
Average Depth	11.45 feet (3.49 meters)
Storage capacity	9343 ac-ft (3×10^9 gal) (11,505,704 m^3)
Surface Area (Full pool)	816 acres
Surface Area (10 ft drawdown)	490 acres
Dam Length	2700 feet (823 meters)
Maximum Depth at Dam	35 feet (10.7 meters)
Tidal Fluctuation	1.9 feet (.58 meter)

SURFACE INFLOW

Table 4-2 compiles available flow data for each tributary to a West Loch Impoundment. While excellent data is available for Waikele Stream, limited data was found for Honuliuli and Kapakahi Streams. Data was extrapolated for Kapakahi Stream using linear regression techniques to correlate Kapakahi flow, Q_k, as a percentage of Waikele flow. An existing 17 year record of springflow was assumed to represent annual flow for this tributary. This data was used to establish a linear relationship (see Figure 4-2) between the dependent variable, Springflow/Q_w, represented as a percentage of the independent variable, Waikele annual flow, Q_w. The resulting equation:

Table 4-2. RESERVOIR INFLOWS

WATER YEAR	RUNOFF WAIKELE	HONOULIULI (acre-feet)	KAPAKAHI	SEEPAGE (ac-ft)	RESERVOIR MEAN RAIN (inches)	RESERVOIR RAINFALL (ac-ft)
1951	30120	6306	998	125	43.115	2932
1952	30120	2110	998	125	12.09	822
1953	15270	1858	799	125	11.155	759
1954	13370	4525	732	125	31.305	2129
1955	44010	5185	670	125	38.945	2648
1956	38660	4016	855	125	27.705	1884
1957	32430	4282	978	125	27.655	1881
1958	33540	3723	964	125	24.61	1673
1959	24760	2135	992	125	13.81	939
1960	30120	2065	998	125	14.935	1016
1961	15310	2365	800	125	13.5	918
1962	18730	3415	896	125	23.14	1574
1963	39530	5695	830	125	38.855	2642
1964	25560	3163	998	125	20.995	1428
1965	40180	6027	810	125	46.17	3140
1966	41690	3633	760	125	26.93	1831
1967	41480	4496	767	125	29.81	2027
1968	39280	5885	838	125	40.6	2761
1969	55980	4058	1210	125	27.37	1861
1970	23920	2510	984	125	18.3	1244
1971	37770	4889	879	125	34.22	2327
1972	29590	4474	1001	125	26.805	1823
1973	14240	1913	764	125	11.125	757
1974	37860	5013	711	125	33.75	2295
1975	26930	3882	1187	125	25.145	1710
1976	28750	2358	1011	125	15.31	1041
1977	14630	2333	818	125	16.37	1113
1978	16400	4216	560	125	26.62	1810
1979	28730	3034	885	125	18.58	1263
1980	40010	4503	955	125	30.15	2050
1981	18120	2143	913	125	14.245	969
1982	55930	6938	1210	125	44.035	2994
1983	27520	1099	1199	125	6.575	447
1984	15070	2535	798	125	15.28	1039
1985	15750	3670	826	125	24.41	1660
1986	20770	3017	818	125	18.74	1274
1987	20230	3978	784	125	26.17	1780
1988	33150	3086	955	125	19.87	1351
1989	39980	5193	1299	125	37.76	2568
1990	31180	3279	1053	125	25.02	1701
1991	42900	3448	715	125	26.34	1791
AVERAGE	30120	3718	940	125		1592

KAPAKAHI FLOW NOMOGRAPH

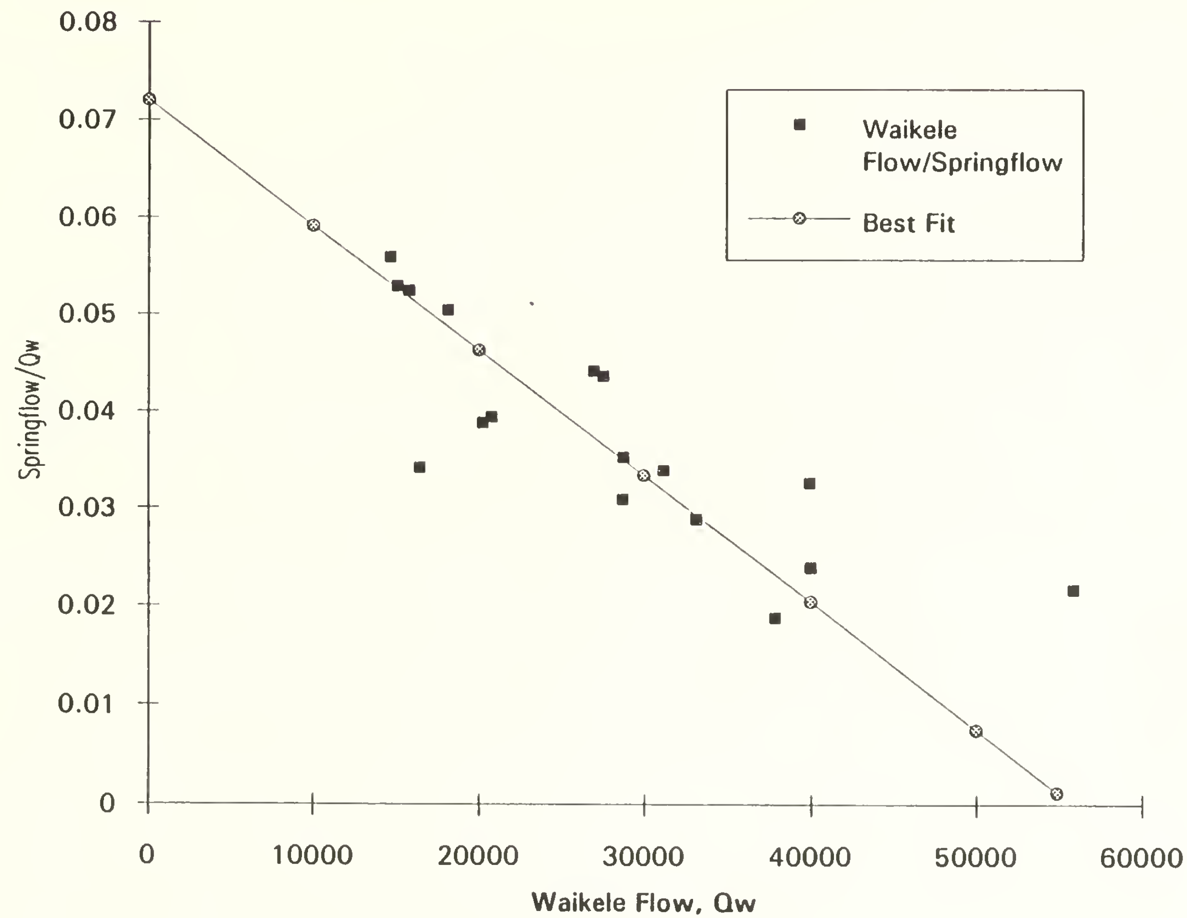


FIGURE 4-2

$$Q_k = (-1.29\times10^{-6} * Q_w + .072) * Q_w \qquad \text{(Eqtn 4-1)}$$

was used to extrapolate Kapakahi flow to correspond with the forty year Waikele record. A correlation coefficient of .9997 assures accurate results. Developing flow data for Honuliuli Stream was a more difficult task because flow was not perennial from 1951-1991 because of past diversions for sugar irrigation. While no diversions are presently recorded with DWRM, field observation indicates significant runoff is retained by agricultural landscaping practices. Previous studies indicate that approximately 22.46% of annual rainfall becomes runoff in this watershed (DLNR, 1979). Table 4-3 compiles available rainfall data for gauging stations within or near the Honouliuli watershed (Figure 4-3). These stations were averaged to determine a mean annual rainfall for this 11 square mile watershed for each year from 1951-1991. It follows from this data that annual flow can be approximated by the following equation:

$$Q_h = (R_h*.2246)\ 11 \text{ sq mi} * 640 \text{ acre/sq mi} \div 12 \text{ in/ft} \qquad \text{(Eqtn 4-2)}$$

where: R_h - Mean Annual Rainfall in inches over Honouliuli Watershed

SEEPAGE

Seepage flows into or out of West Loch were cited as a potential concern in previous feasibility studies (Chang, 1973 and BWS, 1979). While existing data is certainly insufficient to draw hard conclusions, enough data is available to determine that flow gradients surrounding West Loch will cause some seepage into the impoundment (Lee, 1973 and Yuen, 1992). Seepage will probably occur in areas of lagoonal deposits and is unlikely to occur in areas covered by cap rock. Seepage from the northwestern shoreline in the area of the Waipahu Landfill has been estimated at 27,800 gal/dy. This flow is generated along only 1/6 of the total shoreline. caprock deposits cover the northern eastern third of the impoundment shoreline (Yuen, 1992).

Table 4-3. Annual Rainfall from gaging stations within Honouliuli Watershed.

STATION	725.2 725.6	732	733	733.1	734.4	737	738.1 738.4	739	741	743	747	750	807.00	ANNUAL MEAN	RESERVOIR MEAN
YEAR															
1951	63.99	38.24	54.32	ND	ND	41.32	51.16	54.88	40.37	41.84	41.95	44.28	54.10	47.86	43.12
1952	28.57	11.18	20.68	ND	ND	13.35	17.14	15.45	10.34	14.43	9.46	14.72	20.83	16.01	12.09
1953	22.94	10.65	12.47	ND	ND	10.30	16.66	15.55	11.71	10.92	8.67	13.64	21.56	14.10	11.16
1954	43.93	27.40	40.54	ND	ND	31.56	36.31	35.40	27.79	31.33	27.83	34.78	40.87	34.34	31.31
1955	47.53	33.77	35.78	ND	ND	36.47	43.17	41.14	35.14	37.33	38.26	39.63	44.61	39.35	38.95
1956	44.65	26.56	29.12	ND	ND	27.24	33.62	30.56	25.31	27.21	24.74	30.67	35.57	30.48	27.71
1957	40.78	23.65	27.86	ND	ND	25.80	34.20	62.10	24.26	26.62	26.06	29.25	36.87	32.50	27.66
1958	44.08	25.02	26.11	ND	ND	25.76	34.78	28.62	23.00	25.95	22.11	27.11	DI	28.25	24.61
1959	26.10	13.17	14.92	ND	ND	13.56	18.43	15.29	13.44	14.83	12.79	14.83	20.88	16.20	13.81
1960	24.81	11.83	14.34	ND	ND	11.75	DI	15.54	13.96	13.31	14.39	15.48	21.30	15.67	14.94
1961	32.19	13.79	19.06	ND	ND	14.63	ND	20.52	13.22	13.06	13.04	13.96	26.03	17.95	13.50
1962	44.30	24.05	29.34	ND	ND	23.11	ND	31.85	21.87	23.18	22.51	23.77	15.17	25.92	23.14
1963	61.05	37.27	46.49	ND	ND	38.49	ND	46.20	37.59	38.15	37.71	40.00	49.27	43.22	38.86
1964	DI	22.41	26.19	ND	ND	21.85	ND	28.07	19.31	21.85	19.91	22.08	34.30	24.01	21.00
1965	58.87	39.44	44.54	ND	ND	39.55	ND	46.96	41.94	43.63	44.98	47.36	50.16	45.74	46.17
1966	37.61	20.89	28.81	29.01	27.82	24.33	31.41	28.70	20.33	23.35	22.80	31.06	32.29	27.57	26.93
1967	45.82	23.71	33.38	34.83	41.00	28.14	41.52	38.50	22.63	26.69	26.44	33.18	47.74	34.12	29.81
1968	56.19	40.22	43.05	46.98	48.80	41.67	51.11	44.79	37.52	38.90	38.69	42.51	50.17	44.66	40.60
1969	40.50	23.55	31.28	30.60	30.98	29.72	31.45	33.17	25.94	27.75	26.13	28.61	40.67	30.80	27.37
1970	26.88	13.57	17.99	19.89	21.23	16.79	20.04	21.07	13.91	15.33	16.08	20.52	24.37	19.05	18.30
1971	49.22	31.19	34.83	39.12	42.61	32.26	41.25	40.20	25.05	33.98	31.19	37.25	44.17	37.10	34.22
1972	45.47	28.86	41.23	34.72	39.01	31.94	37.74	34.23	26.07	29.28	25.93	27.68	39.23	33.95	26.81
1973	25.05	13.36	12.41	13.69	15.17	13.83	14.07	14.97	11.35	14.53	10.69	11.45	18.08	14.52	11.13
1974	46.10	29.99	38.46	38.69	45.00	33.91	43.40	42.77	26.45	34.53	30.99	36.51	47.82	38.05	33.75
1975	39.25	27.93	29.88	31.87	31.68	28.08	30.44	30.01	23.87	27.46	25.08	25.21	32.26	29.46	25.15
1976	DI	16.27	20.22	20.50	22.52	17.69	20.31	17.47	13.13	18.12	14.44	16.18	DI	17.90	15.31
1977	DI	18.54	17.35	16.37	20.25	16.61	18.77	16.51	14.69	18.07	17.87	14.87	19.58	17.46	16.37
1978	45.75	31.43	32.48	34.95	35.39	30.55	32.97	34.49	25.14	29.20	26.84	26.40	30.33	31.99	26.62
1979	34.70	16.24	22.10	26.64	26.70	19.45	27.61	26.53	14.56	17.59	17.91	19.25	30.10	23.03	18.58
1980	50.60	28.81	30.14	37.62	37.46	30.40	38.54	33.33	27.67	30.09	30.36	29.94	39.30	34.17	30.15
1981	DI	10.96	14.61	17.33	18.59	13.71	21.23	16.35	11.13	14.70	14.15	14.34	22.30	15.78	14.25
1982	DI	44.71	DI	DI	DI	44.64	60.00	52.77	66.77	DI	42.97	45.10	DI	50.99	44.04
1983	DI	7.20	ND	ND	ND	7.20	10.09	7.94	5.01	ND	6.02	7.13	DI	7.23	6.58
1984	ND	ND	ND	ND	ND	ND	ND	ND	14.05	ND	ND	15.28	ND	14.67	15.28
1985	ND	ND	ND	ND	ND	ND	ND	ND	20.36	ND	ND	24.41	ND	22.39	24.41
1986	ND	ND	ND	ND	ND	ND	ND	ND	17.30	ND	ND	18.74	ND	18.02	18.74
1987	ND	ND	ND	ND	ND	ND	ND	ND	21.17	ND	ND	26.17	ND	23.67	26.17
1988	ND	ND	ND	ND	ND	ND	ND	ND	DI	ND	ND	19.87	ND	19.87	19.87
1989	ND	ND	ND	ND	ND	ND	ND	ND	DI	ND	ND	37.76	ND	37.76	37.76
1990	ND	ND	ND	ND	ND	ND	ND	ND	17.53	ND	ND	25.02	ND	21.28	25.02
1991	ND	ND	ND	ND	ND	ND	ND	ND	15.17	ND	ND	26.34	32.69	24.73	26.34
MEAN	41.7381	23.8139	28.709	29.5506	31.5131	25.3261	31.7563	30.9676	22.4628	25.2648	23.9121	26.1546	34.09	27.36	

LEGEND
All data in inches
DI - Data Insufficient
ND- No Data
RESERVOIR MEAN from Station 747 &750

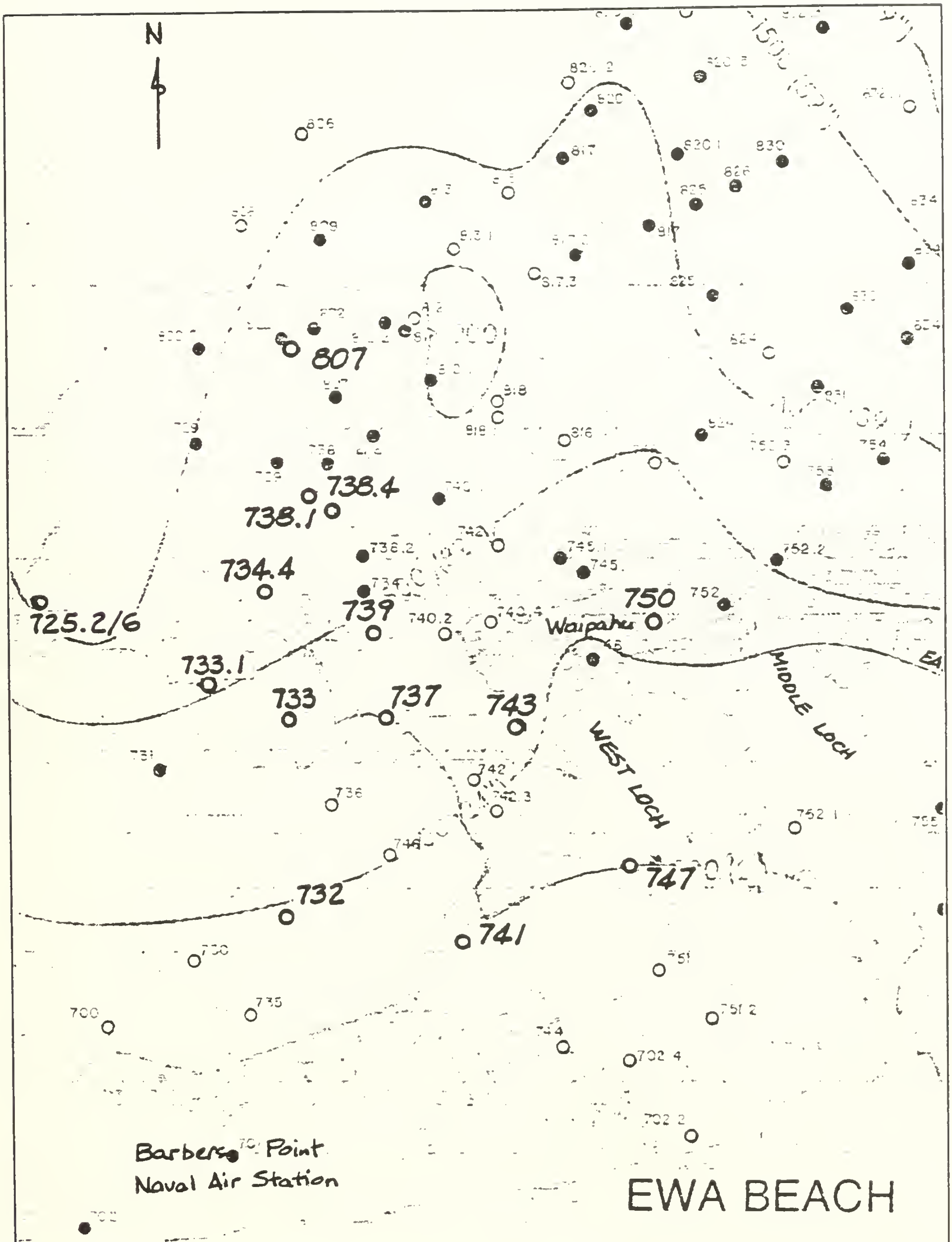


FIGURE 4-3
Source: (DLNR, 1982)

HONOULIULI WATERSHED
RAIN GAUGING STATIONS

Annual seepage can therefore be roughly approximated as:

27,800 gal/dy * 6 *2/3 *365 dy/yr ÷ 7.48 gal/cf ÷ 43560 sf/ac = 125 ac-ft/yr

Compared to other flows, seepage into the reservoir along its perimeter is negligible. In Chapter Five it will be shown that seepage from the bottom is also negligible.

RESERVOIR RAINFALL

Rainfall over the impoundment represents another significant source of water. This was estimated by averaging the annual rainfall at gauging stations 747 & 750 (Figure 4-3) and multiplying by the surface area of the reservoir.

EVAPORATION

The only significant water loss occurs from evaporation, which has been estimated at 2097 acre-feet (Fok, 1992). This reservoir loss is include along with anticipated outflows from water production and spillway flow in Table 4-4. If design modeling is justified a more accurate estimate can be obtained using the following equation to relate evaporation, E_V, to actual annual precipitation (Thomann, 1987):

$$E_v = \frac{1}{A_s}\left[\frac{\Delta V}{\Delta t} + Q_{in} - Q + P \cdot A_s\right] \qquad \text{(Eqtn 4-3)}$$

where:

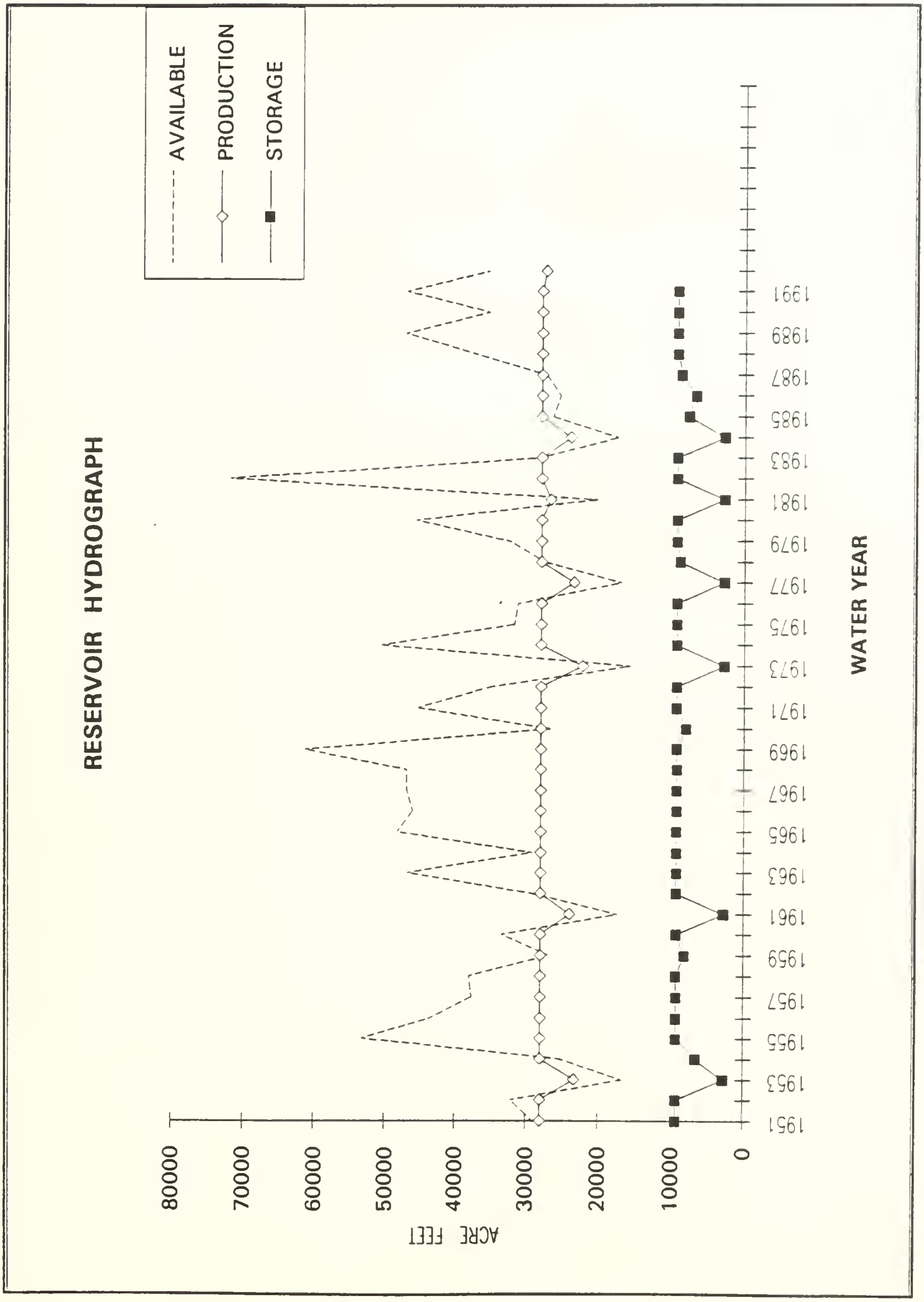
A_S-- Reservoir surface area
P -- Annual Precipitation
Q -- Annual Production + Spillway Overflow

RESERVOIR HYDROGRAPH

Using the data from Tables 4-2 & 4-4, a simulated reservoir hydrograph can be developed (Figure 4-4) to estimate the reliable production capacity and the related drawdown or spillway overflow.

Table 4-4. RESERVOIR OUTFLOWS

WATER YEAR	EVAPORATION (ac-ft)	AVAILABLE WATER (ac-ft)	WATER PRODUCTION (ac-ft/yr)	SPILLWAY Q/ DRAWDOWN (ac-ft)	RESERVOIR STORAGE (ac-ft)
1951	2097	29042	28005	1037	9343
1952	2097	32079	28005	4074	9343
1953	2097	16713	23243	-6530	2813
1954	2097	25314	28005	-2691	6652
1955	2097	53233	28005	25228	9343
1956	2097	43443	28005	15438	9343
1957	2097	37599	28005	9594	9343
1958	2097	37928	28005	9923	9343
1959	2097	26854	28005	-1151	8192
1960	2097	33378	28005	5373	9343
1961	2097	17421	23951	-6530	2813
1962	2097	29172	28005	1167	9343
1963	2097	46726	28005	18721	9343
1964	2097	29177	28005	1172	9343
1965	2097	48185	28005	20180	9343
1966	2097	45942	28005	17937	9343
1967	2097	46798	28005	18793	9343
1968	2097	46792	28005	18787	9343
1969	2097	61137	28005	33132	9343
1970	2097	26687	28005	-1318	8025
1971	2097	45211	28005	17206	9343
1972	2097	34916	28005	6911	9343
1973	2097	15702	22232	-6530	2813
1974	2097	50438	28005	22433	9343
1975	2097	31738	28005	3733	9343
1976	2097	31188	28005	3183	9343
1977	2097	16922	23452	-6530	2813
1978	2097	27544	28005	-461	8882
1979	2097	32402	28005	4397	9343
1980	2097	45546	28005	17541	9343
1981	2097	20172	26702	-6530	2813
1982	2097	71631	28005	43626	9343
1983	2097	28293	28005	288	9343
1984	2097	17470	24000	-6530	2813
1985	2097	26464	28005	-1541	7802
1986	2097	25448	28005	-2557	6786
1987	2097	27357	28005	-648	8695
1988	2097	37218	28005	9213	9343
1989	2097	47068	28005	19063	9343
1990	2097	35242	28005	7237	9343
1991	2097	46882	28005	18877	9343
AVERAGE	2097	35328.58154	27408.66629		



RESERVOIR HYDROGRAPH
AVAILABLE
PRODUCTION
STORAGE
ACRE FEET
80000
70000
60000
50000
40000
30000
20000
10000
0
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
WATER YEAR

"Available Water", W_a, is determined from the following equation:

$$W_a = Q_w + Q_h + Q_k + S + R - E - D_{n-1} \qquad \text{(Eqtn 4-4)}$$

where: Q_w -- Annual Runoff from Waikele Stream
Q_h -- Annual Runoff from Honouliuli Stream
Q_k -- Annual Runoff from Kapakahi Stream
S -- Seepage
R -- Reservoir Rainfall
E -- Evaporation from Reservoir
D_{n-1} -- Drawdown from Previous Year

From Figure 4-4 it is apparent that:

1) Average annual potable water production of 24.47 mgd could have been sustained throughout the 40 year study period without drawdown,
2) 25 mgd production could have been sustained during 80% of the period, while limiting reservoir drawdown to normal tidal fluctuation (2 ft),
3) During 85% of the period 25 mgd production could have been sustained by allowing a 10 foot reservoir drawdown.

Application of the Rippel mass curve analysis confirms the sustainability of a 25 MGD withdrawal (Figure 4-5) and indicates that a storage capacity of 25,910 acre-feet or about 10 months supply, would be necessary to guarantee an uninterrupted supply without drawdown during drought conditions (Clark, et al., 1990). Since this impoundment is intended as an alternative source, it will certainly be more cost effective to use sound reservoir management practices to optimize the available storage capacity.

Table 4-5. RIPPL MASS-CURVE

WATER YEAR	INFLOW (ac-ft)	DRAFT 25MGD (ac-ft)	SAFE YIELD (ac-ft)	CUMULATIVE INFLOW (ac-ft)	DEFICIENCY (ac-ft)	CUMULATIVE DEFICIENCY (ac-ft)
1951	40482	30102	30102	40482	-10380	0
1952	34176	30102	60204	74658	-4074	0
1953	18810	30102	90306	93468	11292	11292
1954	20881	30102	120408	114348	9221	20513
1955	52638	30102	150510	166987	-22536	0
1956	45540	30102	180612	212527	-15438	0
1957	39696	30102	210714	252223	-9594	0
1958	40025	30102	240816	292248	-9923	0
1959	28951	30102	270918	321200	1151	1151
1960	34324	30102	301020	355524	-4222	0
1961	19518	30102	331122	375042	10584	10584
1962	24739	30102	361224	399782	5363	15946
1963	48823	30102	391326	448604	-18721	0
1964	31274	30102	421428	479878	-1172	0
1965	50282	30102	451530	530161	-20180	0
1966	48039	30102	481632	578199	-17937	0
1967	48895	30102	511734	627095	-18793	0
1968	48889	30102	541836	675983	-18787	0
1969	63234	30102	571938	739218	-33132	0
1970	28784	30102	602040	768002	1318	1318
1971	45990	30102	632142	813992	-15888	0
1972	37013	30102	662244	851004	-6911	0
1973	17799	30102	692346	868803	12303	12303
1974	46005	30102	722448	914808	-15903	0
1975	33835	30102	752550	948643	-3733	0
1976	33835	30102	782652	981928	-3183	0
1977	19019	30102	812754	1000947	11083	11083
1978	23111	30102	842856	1024058	6991	18073
1979	34038	30102	872958	1058097	-3936	14137
1980	47643	30102	903060	1105740	-17541	0
1981	22269	30102	933162	1128009	7833	7833
1982	67198	30102	963264	1195207	-37096	0
1983	30390	30102	993366	1225597	-288	0
1984	19567	30102	1023468	1245164	10535	10535
1986	22031	30102	1053570	1267195	8071	18606
1986	26004	30102	1083672	1293199	4098	22704
1984	26897	30102	1113774	1320095	3205	25910
1983	38667	30102	1143876	1358762	-8565	17345
1986	49165	30102	1173978	1407927	-15963	0
1986	37339	30102	1204080	1445265	-7237	0
1991	48979	30102	1234182	1494245	-18877	0

Rippl Mass-Curve

MASS LOADING

To estimate the ultimate quality of impounded surface waters it is necessary to determine the mass loading rates for each inflow. The following equation provides a mass balance that can be used to estimate the impoundment concentration, C_i, for each of the nine critical water quality parameters:

$$Q_i C_i = Q_w C_w + Q_h C_h + Q_k C_k + S C_s + R C_r \qquad \text{(Eqtn 4-5)}$$

where:	$C_{w,h,k,s,r}$	--	Average concentration of each critical water quality parameter from samples of all inflows
	Q_i	--	Annual inflow to reservoir
	$Q_{w,h,k}$	--	Annual Runoff from each tributary stream
	S	--	Annual Seepage
	R	--	Annual Reservoir Rainfall

Unfortunately, while concentration data for Waikele Stream is abundant, existing data on the nine critical parameters for the other inflows is sparse. Table 4-5 summarizes the existing data. Data for Honouliuli is based on a single sample (USGS, 1981), while Kapakahi data is obtained from Pearl Harbor Springs measurements and a study of Waipahu Landfill (USGS, 1981 and Lee, 1973). Groundwater values are obtained from wells samples surrounding West Loch found in several studies (USGS, 1983; Hufens, 1980, Lohn, 1952). Rainwater is normally low in all minerals (Tchobanoglous, 1987).

Table 4-5. Mean Values of Critical Water Quality Parameters

Parameter	Units	Waikele	Honouliuli [a]	Kapakahi	Groundwater	Rainfall
COLIFORM	col/100ml	6136			< 100[b]	< 1
TURBIDITY	NTU	6.25	1800		.07[c]	< 1
TDS	mg/l	227	75[d]	657[d]	400[d]	
MANGANESE	ug/l	52.41			<	< 1
LEAD	ug/l	3			< 5	< 1
HARDNESS	mg/l	57.76			229[e]	
IRON	ug/l	50.83				< 1
ALUMINUM	ug/l	19.95				< 1
CHLORIDES	mg/l	61.14		6366	225	

[a] Based on a single sample from (USGS. 1981).
[b] From Table 3.1 (Tchobanoglous, 1987)
[c] Based on a single sample from Table 6.2-1 (USGS, 1983)
[d] Based on conversion from Electrical Conductivity measurements using TDS = .65 *EC (USGS, 1981)
[e] Mean value of two samples from each of ten wells surrounding West Loch (USGS, 1983 and Hufens, 1980)

It is apparent from Table 4-3 that available data is insufficient for all inflows except Waikele Stream. Therefore, substantial data collection will be required to accurately model impoundment effects. Since Waikele accounts for 80% of the flow that would contribute to a West Loch impoundment, these average concentrations will be used as the baseline for this approximation. It should be noted that the temporal loading variability of each inflow should be considered if development of a design model is justified (Thomann, 1987). It is likely that Waikele and Kapakahi Streams flows, as well as seepage, will provide continuous mass loading , while Honouliuli Stream and reservoir rainfall will be intermittent.

TEMPERATURE

Temperature profiles are important to determine the likelihood of reservoir stratification, gas and mineral solubility, growth and respiration rates as well as the chemical or biological reaction rates for each critical parameter (Tchobanoglous, 1987). Continuous temperature data is available only for Waikele Stream (USGS, 1981). As

expected for a tropical stream, it demonstrates negligible seasonal temperature variation. The average monthly mean temperature varies only 2.25°C (4°F) from 21.75°C in January and February to 24°C in July. The extreme range of daily temperatures is a modest 10.5°C (19°F) from 17.5°C in January to 28°C in May. Although no specific data is available for other inflows, the data for West Loch, infers little variation (Morris, 1973). The mean monthly temperature for Pearl Harbor varies 5°C (from 23.1°C in February to 28.2°C in September). Extreme temperatures in West Loch range from 19.8 to 29.7°C on the surface and from 20.4 -29.4°C on the bottom. The warmer temperatures are attributable to solar warming that occurs during the long retention times in the relative quiescent estuary. The data also suggests a spatial variation, with warmer mean temperature in the shallow areas along the shoreline.

STRATIFICATION

A previous study describes Pearl Harbor as "a two layer flow estuary with vertical mixing. The main thermocline and halocline occur at a depth of 1.5 - 5 meters. The less dense freshwater from stream runoff predominates the top layer. Circulation is driven by a combination of wind, tide, fresh and saltwater inflows. Water column stability determines the mixing efficiency of these driving mechanisms. Elevated temperatures and freshwater in the surface layer generally increase stability: However winter solar heating of the upper layer can decrease stability near the head of the lochs because stream influx is cooler than the harbor waters" (Evans, 1974). Although West Loch was specifically excluded from this study, subsequent research indicates that geographical configuration and topography suggest that particle mixing is probably quite slow and bottom residence time high. Since the longitudinal axis of West Loch lies perpendicular to the trade winds the broad upper reaches are more susceptible to vertical mixing (Turner, 1975). Impoundment will obviously greatly

alter the present conditions by excluding tidal and saltwater influx from the system. This change when combined with tropical temperatures may reduce or eliminate stratification. One-dimensional models are generally adequate to describe thermal change in small stratified impoundments of less than 50 km length. The following equation has been developed to confirm this approach (Orlob, 1983):

$$F_r = \frac{l}{d} \cdot \frac{Q}{V} \left(\frac{\rho_0}{g\beta} \right)^{1/2} \qquad \text{(Eqtn 4-6)}$$

where:

F_r	--	Froude Number
l	--	Impoundment length (2377 m)
d	--	Average impoundment depth (3.49 m)
Q	--	Impoundment discharge (25 mgd=1.1 m^3/s)
V	--	Impoundment volume $=lbd$ (11,525,704 m^3)
ρ_0	--	reference density (997.048 kg/m)
g	--	acceleration of gravity (9.81 $kg \cdot m^2$)
β	--	density gradient = $\Delta\rho/d$(.235/3.49=.0673)

If $F_r << 1/\pi$, the impoundment can be considered well stratified and the 1-dimensional model is appropriate. Values of F_r. > 1.0 define fully-mixed systems. If $0.1 < F_r < 1.0$, then the impoundment is probably weakly stratified and requires a two dimensional model Substituting proposed reservoir parameters, noted in parenthesis above, yields:

$$F_r = \frac{2377\text{m}}{3.49\text{m}} \cdot \frac{1.1\,\text{m}^3/\text{s}}{111{,}525{,}704\,\text{m}^3} \left(\frac{997.048\,\text{kg}/\text{m}^3\,\text{k}}{9.81\,\text{kg}/\text{m}^2 \left(\frac{.235\,\text{kg}/\text{m}^3}{3.49\text{m}} \right)} \right)^{1/2} = .002526 << .318$$

This approach suggests that West Loch will remain stratified after impoundment. Although this equation does consider tropical temperature as a function of density change and detention time it does not take into account the consistently strong trade winds that provide the most significant mixing effect. Additionally prudent design practice would locate both intake and spillway structures so as to promote full mixing (Orlob, 1987). Therefore this analysis will presume a completely mixed system to evaluate the fate of critical parameters during impoundment. While this assumption may be an over simplification of the actual conditions, it does provide a valuable estimate of the ultimate concentration of both dissolved and suspended substances in the vertical water column (Thomann, 1987). A finite segment, steady-state model should be used for this two-layered, stratified reservoir during the design phase to better understand the vertical and horizontal gradients that may prevail near shore, in embayments, seasonally, or during periods of high drawdown.

DETENTION TIME

The length of time that freshwater will be retained in the impoundment directly impacts the fate of each of the critical water quality parameters. Detention time, t_d, is a function of reservoir storage and outflow and can be approximated by the following equation assuming a 25 mgd withdrawal rate:

$$t_d = \frac{V}{Q} = \frac{11{,}505{,}704\,\mathrm{m}^3}{1.1\ \mathrm{m}^3/\mathrm{s} \times 86{,}400\ \mathrm{s}/\mathrm{d}} = 121\ \text{days} \qquad \text{(Eqtn 4-7)}$$

The empirical equation below has been developed from a study of 36 lakes and reservoirs to estimate the natural detention time as a function of drainage area, DA, and lake surface area, SA (Bartsch, 1978).

$$\log t_d = 4.077 - 1.1771 \log \frac{\mathrm{DA}(56.7\ \mathrm{sm} \times 640\ \mathrm{ac}/\mathrm{sm})}{\mathrm{SA}(816\ \mathrm{ac})} = 137\ \text{days} \quad \text{(Eqtn 4-8)}$$

This indicates that detention time would be shortened about 10% if impoundment is implemented

GENERAL CHARACTERIZATION of IMPOUNDMENT EFFECTS

Storage and sedimentation of surface water in reservoirs often improves the quality of the raw water but sometime adverse effects can occur (Geldreich, 1980). Water quality improvements are promoted by warm water temperatures. Long retention times aid self-purification that results from physical actions such as dilution, sedimentation, and biodegradation, while thermal stratification can inhibit uniform mixing and result in temporary water quality degradation during "overturn" (Geldreich, 1990).

Coliforms

The literature demonstrates that fecal contamination is reduced during impoundment by natural dispersion and sedimentation so it appears that Mr. Teas' presumption is incorrect (Teas, 1988). A 1-2 log reduction is commonly experienced in many impoundments (Geldreich, 1980). Tropical reservoirs promote a stable relationship between decomposition bacteria and algal photosynthesis that results in highly effective water purification. Lake Carrizio which supports a significant area of water hyacinth plants achieves a 99% reduction in Total Coliform levels found in tributary streams (from 10^6 to 10^4 colonies/100ml) with no other treatment and a detention time of only 55 days(Brown, 1979). This indicates that the mean coliform concentration from Waikele Stream could be expected to decrease to a range of 61-610 colonies/100 ml. This well within the raw water treatment limits for potable supplies and could conceivable satisfy the accepted criteria of 100 colonies / 100ml for disinfection only. However, storm water runoff can increase coliform densities tenfold (Geldreich, 1990 and 1980). Coagulation, flocculation, sedimentation and filtration are recommended prior to disinfection to control these variations .

Turbidity

Previously observed values of turbidity in West Loch are of the same order of magnitude as those measured in Waikele Stream. Impoundment of stream flows by the Tennessee Valley Authority has resulted in as much as a 61 percent reduction in turbidities (Churchill, 1957). Figure 3-2 illustrates the large fluctuations in turbidity that can occur during storm events. The greatest benefit of impoundment is the rapid dispersion and recovery from high storm turbidity that the sedimentation capacity of the reservoir provides. Applying conservative 50% reduction factor to both the mean and maximum Waikele turbidities results in a treatment range of 3.25-380 NTU.

Total Dissolved Solids

This characteristic is not expected to change significantly as a result of impoundment even though several low percentage constituents will be reduced. Raw water concentration should approximate the mean of 234 mg/l because maximum observed samples will be diluted by the large reservoir storage capacity.

Manganese

A well mixed reservoir will promote sorption of manganese into the sediment, thereby reducing the concentrations of manganese in the water column (Wilhm, 1979). This oxidation reaction is greatly dependent on dissolved oxygen content (DO) so reduction during impoundment varies. The treatment range of raw water should then correspond to 52 ug/l, the mean value of Manganese from Waikele Stream.

Lead

Naturally occurring lead carbonates and hydroxides are very insoluble and reductions of 90% are typical as result of sedimentation(Gumerman, 1976). This would reduce even the maximum observed stream concentration of < 10 ug/l to well below the current MCL.

Iron

Mean concentrations of 51 ug/l are only marginally higher than the SMCL of <50 mg/l. Under normal oxygen levels, iron remains in the ferric state and will precipitate with other coagulable substances during the natural sedimentation process (Weiss, 1960). It is probable that iron concentrations will not require treatment after impoundment .

Aluminum

Mean concentrations 20 ug/l are well below the AWWA goal of 50 ug/l. Maximum observed values are not of significant concern because, along with Iron, these trivalent cations will aid in the coagulation of colloids (Davis, 1991). high peak stream concentrations will be diluted by the large reservoir storage capacity. Any residual concentration will slightly reduce alum requirements during treatment.

Hardness

This characteristic is not expected to change significantly as a result of impoundment. The dilution effect will serve to negate occasional peak concentrations so the mean value of 58 mg/l is a likely estimate of prevailing impoundment concentration. This is below the AWWA drinking water goal of 80 mg/l so treatment is not necessary.

Chlorides

Existing measurements of Kapakahi Stream (Table 4-4) are artificially high because mixing with the brackish water of West Loch estuary will not occur after impoundment. Correspondingly, the salinity of groundwater seepage will reduce since isochors would be expected to change as the result of impounding freshwater in West Loch. Leeching would be expected across the sediment-water interface for 580 days after the impoundment was filled with freshwater (Fok, 1992). After leeching ceases

the reservoir would be expected to approximate the 62 mg/l mean concentration of Waikele Stream. This is well below the 250 mg/l SMCL.

SUMMARY

The literature clearly demonstrates that impoundment will improve the water quality of the surface runoff that will be retained. Of the nine parameters considered total coliform, turbidity, manganese and TDS will definitely require treatment to achieve AWWA drinking water goals which are more stringent than the NPDWS. Although lead concentrations will likely satisfy existing treatment goals the proposed 0 ug/l at the tap goal dictates that treatment be provided. Iron, aluminum, hardness and chloride concentrations will not require further treatment.

While this analysis has been concerned with the fate of parameters critical to the water treatment process, it is important to note that development of a physical model of this impoundment should also address a multitude of physical, chemical, and biological factors including the potential for eutrophication, dissolved oxygen and algal growth problems. The extensive sampling, testing and data analysis that will be required could best be accomplished under the non-point source pollution demonstration program. This makes the Pearl Harbor Estuary Interagency Committee (Water & Technology, Inc., 1991) the logical group to provide an impartial, initial evaluation of this proposal.

REFERENCES

Andelman, A.B., 1975. "The Effect of Water Treatment and Distribution on Trace Element Concentrations". Chemistry of Water Supply Treatment, and Distribution, author, Alan J. Rubin. Ann Arbor Science Publishers, Ann Arbor, Michigan.

Brown, R.A and Jobin, W.R, 1979. *"Water Purification in Some Hydroelectric Reservoirs of Puerto Rico"*, Center for Energy and Environment, Puerto Rico, Water Purification Control Federation Conference, Houston Texas.

BWS , July 20, 1979. *West Loch Impoundment Utilizing Water From Waikele and Waiawa Stream.* City and County of Honolulu, Hawai'i.

Clark, J.W., Viessman, W. & Hammer, M.J., 1990. Water Supply and Pollution Control. Third Edition, Harper & Row, Publishers, New York, New York.

DLNR, 1979. Hawai'i Water Resources Regional Study: Hawai'i Water Resources Plan, State of Hawai'i.

DLNR, 1982. *"Median Rainfall"*. Department of Water and Land Development, Circular C-88. State of Hawai'i.

Evans, E.C., 30 August 1974. *"Pearl Harbor Biological Survey - Final Report"* Hawai'i Laboratory, Naval Undersea Center, San Diego, California

Fok , Y. -S. and Murabayashi, E.T. September, 1992. *""Impoundment of Stream Flow in West Loch, Pearl Harbor, Oahu, Hawai'i: A Feasibility Study""*. Technical Report #192. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Geldreich, E.E., Nash, H.D., Spino, D.F., and Reasoner, D.J., January, 1980. *"Bacterial Dynamics in a Water Supply Reservoir: A case Study"*. American Water Works Association Journal, Vol. 72:1, Denver, Colorado

Gower, A. M., 1980. Water Quality in Catchment Ecosystems, John Wiley & Sons, Chicester, England.

Gumerman, R.C., Culp, R.L. and Hansen, S.P. August 1979. *"Estimating Water Treatment Costs - Volume 1 Summary"*. EPA publication EPA-600/2-79-162a, Environmental Protection Agency, Cincinnati, OH.

Hufens, T.H., Eyre, P., McConachie, W., 1980. *"Underground Residence Times and Chemical Quality of Basal Groundwater in the Pearl Harbor and Honolulu Aquifers"*. Technical Report #129. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i

Lee, C.R., August 1973. *"Hydrogeology of the Waipahu Landfill Area"*. Graduate Thesis for Master of Science in Geology and Geophysics, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Lohn, E.H. and Love, S.K., 1952. "The Industrial Utility of Public Water Supplies in the US" USGS Water Supply Paper #1299, Department of the Interior, Washington, D.C.

Morris, D.E., Surface, S.W., and Murray, J.P., 1973. *Navy Environmental Protection Data Base: Completion Report for the Pearl Harbor, Hawai'i Study*

Covering the Test Period through Calendar Year 1972. Naval Civil Engineering Laboratory, Port Hueneme, California

Orlob, , 1983. Mathematical Modeling of Water Quality: Streams, Lakes, and Reservoirs. John Wiley & Sons, New York, New York.

Teas, H. J., 01 March 1988. *"Evaluation of A Plan for Impoundment of Freshwater in West Loch for Irrigation".* Appendix II, Draft Technical Report. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Tchobanoglous, G. and Schroeder, E.D., February, 1987. Water Quality: Characteristics, Modeling, Modification. Adison-Wesley Publishing Company, Menlo Park, California.

Thomann, R.V. and Mueller, J.A., 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row, Publishers, Inc., New York, New York

Turner, B.W., August, 1975. *"Mineral Distribution within the Sediments of Pearl Harbor".* Graduate Thesis for Master of Science in Geology and Geophysics, University of Hawai'i at Manoa, Honolulu, Hawai'i.

United States Geological Survey (USGS), 1981. *"Summary of Available Data on Surface Water, State of Hawai'i, Volume 4".* Open-File Report 81-1056. US Department of Interior, Honolulu, Hawai'i.

USGS, 1983. *"Investigation of Waikele Well No. 2401-01, Oahu, Hawai'i: Pump Testing, Well Logs and Water Quality".* Water Resources Investigation Report # 83-4089, Department of the Interior, Washington, D.C.

Water Engineering & Technology, Inc., September 1991. *"Nonpoint Source Sediment Pollution Investigation of the Pearl Harbor Drainage Basin".* Pearl Harbor Estuary Program Interagency Committee, Honolulu, Hawai'i.

Weiss, C.M. and Oglesby, R.T., August, 1960. *"Limnology and Quality of Raw Water in Impoundments".* Public Works: City, County, and State, Vol.91, Public Works Journal Corp, East Stroudsburg, PA.

Wilhm, J., Barker, D., Cover, E., Clay, E. and Fehler, R., December 1979. *"Effects of Destratification on Sediment Chemistry and Benthic Macroinvertebrates in Ham's Lake".* Oklahoma Water Resources Research Institute, Oklahoma State University, Tulsa OK

Yuen, G.A.L. and Associates, 1989. *"Groundwater Resources and Sustainable Yield, Ewa Plain Caprock Aquifer"*. Commission on Water Resources Management, Department of Land and Natural Resources, Honolulu, Hawai'i.

CHAPTER FIVE
Facilities Requirements

Since treatment to potable standards appears to possible, it is time to determine what facilities would be necessary to develop this alternative surface water supply for Oahu.

IMPOUNDMENT STRUCTURE

Previous reviews of impoundment studies have questioned the feasibility because of inadequate surface inflow, possible seepage problems, conflict with existing land use and high cost (Chang, 1973, BWS, 1979 and Fok, 1992). Chapter Four has demonstrated that past flow records indicate that impoundment can support a 25 mgd source. Seepage, land use concerns and cost reduction alternatives will be addressed now.

Original cost estimate for an earthen dam was $12 million (Chang, 1973). A subsequent study called attention to the potential for leakage and foundation problems due to the limited knowledge of the geologic substructure and estimated dam construction costs at twice this amount (BWS, 1979). Fok and Murabayashi have proposed using hydrostatic membrane technology to achieve significant cost savings. These proposals did not consider the substantial benefits that could be realized by the multi-use of the impoundment structure for access to Waipio Peninsula. Perhaps this goal could be achieved by using a dam structure of limited cross section supported by sheet pile and constructed of dredged material (Figure 5-1). This construction method is better suited to the existing site conditions because it can prevent conflict with existing shipping channels and reduce initial cost, but is construction feasible?

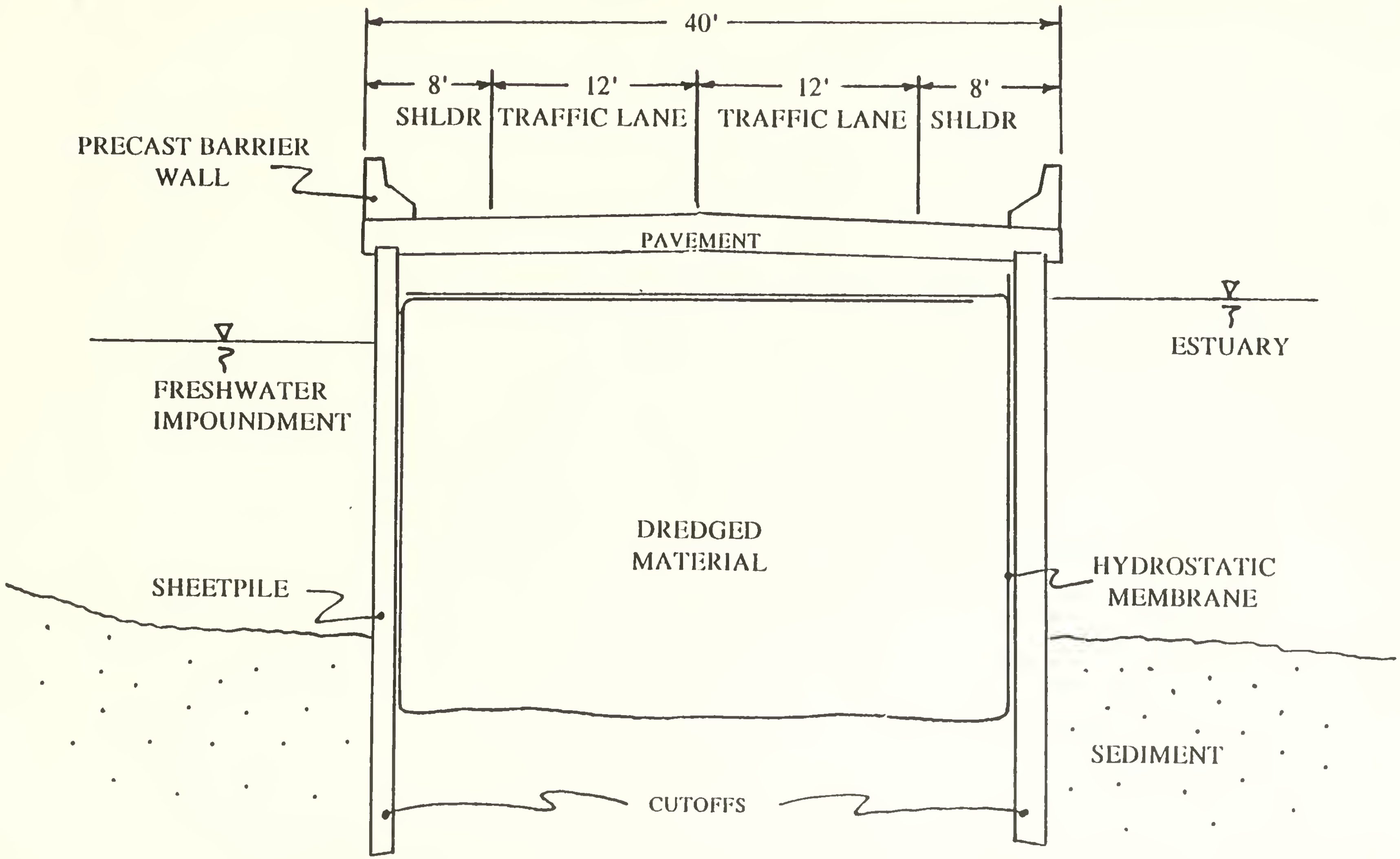


FIGURE 5-1 LIMITED CROSSECTION EARTH DAM

Hydraulically-placed fills have achieved widespread use for marsh reclamation and embankment construction (Whitman, 1969). Arthur Casagrande has noted that it is an economical method for dam construction and problems which have discredited this technique, have been overcome by unique construction techniques (______, 1968). Problems encountered with hydraulic fill sea walls placed over soft mud have been studied extensively and effective solutions have been implemented using sheet piles and sand blankets (Terzaghi, 1967).

The use of sheet piles to support the fill serves several purposes:

- eliminates extensive excavation of soft clays
- reduces the size and weight of the structure
- controls placement of hydraulic fill;
- controls turbidity and dewatering during construction;
- controls sinking failure;
- cuts off seepage flow;
- cuts cost and construction time.

A review of existing geological data is a logical starting point to assess the feasibility of this design concept for West Loch.

Geologic Conditions

Discussions of the geologic evolution of Pearl Harbor abound and will not be regurgitated here for the sake of brevity. John Mink has provided useful insight into the substructure of the Puuloa Sector of the Ewa Plain by constructing a geologic crossection based on existing drillhole logs (Figures 5-2 & 5-3). This reveals that surface soils covers a fossil reef along the Ewa shoreline of West Loch. This layer varies in depth from 0'-200' and overlies alternating layers of mud, muddy reef and marl (Yuen, 1992).

Although her work does not specifically cover the West Loch area, Munro's description of the engineering properties of Lagoonal Deposits within Pearl Harbor is pertinent (Munro, 1981). These sediments occur in an unconsolidated state throughout the

channelways of all lochs and vary in thickness from 30' to over 100'. This material is very soft to soft based on the Unified Classification System and is generally poorly suited for foundations due to its high compressibility, poor shear strength and low permeability. Recommended allowable bearing pressures are usually 1000 - 1500 psf. Mineral distribution throughout West Loch indicate deposition of silts and sands in the deltas near the stream mouths of Honouliuli and Waikele, while high concentrations of clay minerals predominate the channelways (Turner, 1975). More specific data is available from soil borings done during the design of the Pearl City sewage forced main. This report indicates that very soft, partly organic, gray clay formation is about 30' thick. This material displays an increase in resistance from 30-65' but still exhibits poor compressive strength. Shear strength is approximately 200 psf and dry strength is described as medium. Water contents range from 103 -184% and are consistently higher than the liquid limit (Lum, 1975). Based on limited consolidation tests of these samples a rough approximations of unconsolidated & consolidated unit weight and void ratio are:

$$\gamma_{sat} = 82.6 \text{ pcf} \qquad e_o = 3.52$$

$$\gamma_{consol} = 96 \text{ pcf} \qquad e = 2.43$$

Design Considerations

This impoundment structure must satisfy the following design considerations:

- prevent seepage of saltwater from the estuary;
- prevent overtopping from tidal, tsunami, flood, ship wake and waves generated by explosive blast;
- provide adequate width to allow two lane traffic with adequate shoulder width to accommodate dam maintenance and vehicle breakdown.

Seepage from under the dam foundation is a primary concern because high seepage volumes could adversely affect the salinity of the impounded freshwater. The easiest way to control this problem is to limit drawdown in the reservoir. A hydrograph of annual runoff from the past forty years indicates that drawdown can be limited to 10' and still provide a 25 mgd potable source.

Dam freeboard height must be sufficient to prevent overtopping. According to the Federal Emergency Management Agency (FEMA) tidal variation is only two feet (1.9' at Mean Highest High Water) and tsunami inundation is not anticipated within West Loch (FEMA, 1990). Ship wake would not be expected to exceed three feet during tugboat maneuvering of ammunition ships within the turning basin of Wharves 1-3. A wave generated by explosive detonation is of concern because the proposed impoundment is located within the explosive safety quantity -distance (ESQD) arc of the naval magazine. Prediction of wave heights from a design explosion in shallow water is currently the subject of research (Wang, 1987 and 1992; Le Mehaute, 1970). For the purpose of this review a freeboard height of fifteen feet will be assumed to prevent overtopping in this worst-case scenario.

A forty foot dam width should be sufficient to accommodate two twelve foot travel lanes with eight foot shoulders.

Potential Problems

Existing data is inadequate and consequently will allow only the roughest quantitative approximation of the structural problems that must be analyzed during design of this impoundment structure. An initial review of the literature indicates the following areas of concern:

- sensitivity of clay sediments to settlement from defloculation
- resistance to sinking and spreading failures
- minimize overburden pressure on underlying soft clay substrata to control settlement;

Turner (1975) has attributed the areal distribution of clay particles to increasing salinity in deeper reaches of West Loch. As salinity increases downstream these small suspended particles flocculate and settle to form porous marine sediment oriented in an "edge-to-face" array (Terzaghi, 1967). These sediments are characterized by high compressibility, loose structure and exhibit a high water content greater than its liquid limit. The clay fraction varies from 30-50 percent and is composed mainly of mica and chlorite with a coarse fraction (50-70%) of quartz, feldspar and amphibole minerals (Kazi, 1973). If these sediments are subjected to leaching of freshwater they may deflocculate and reorient in parallel arrays. This causes some initial compression which may decrease permeability and in some cases result in piping in areas of high gradient (Cedergren, 1989). A loss of shear strength also occurs. In highly sensitive Scandinavian and Canadian clays subsequent loading have caused soil liquefaction that resulted in flows of great distance with little elevation difference. The high water content (Lum, 1975) and mineral distribution (Turner, 1975) of sediments in West Loch suggest extensive subsurface exploration and soil testing will be necessary.

The failure of a structure constructed on a a soft clay generally approximates a base failure along the mid point circle (Terzaghi, 1967). If we assume a worst-case, the radius of failure would be located at the base of the dam. Settlement, S, of the structure continues over time and can become very great. Using Terzaghi's equation:

$$S = H\frac{\Delta e}{1+e_0} = H\frac{C_c}{1+e_0}\log\frac{\bar{p}_0 + \Delta p}{\bar{p}_0} \qquad \text{(Eqtn 5-1)}$$

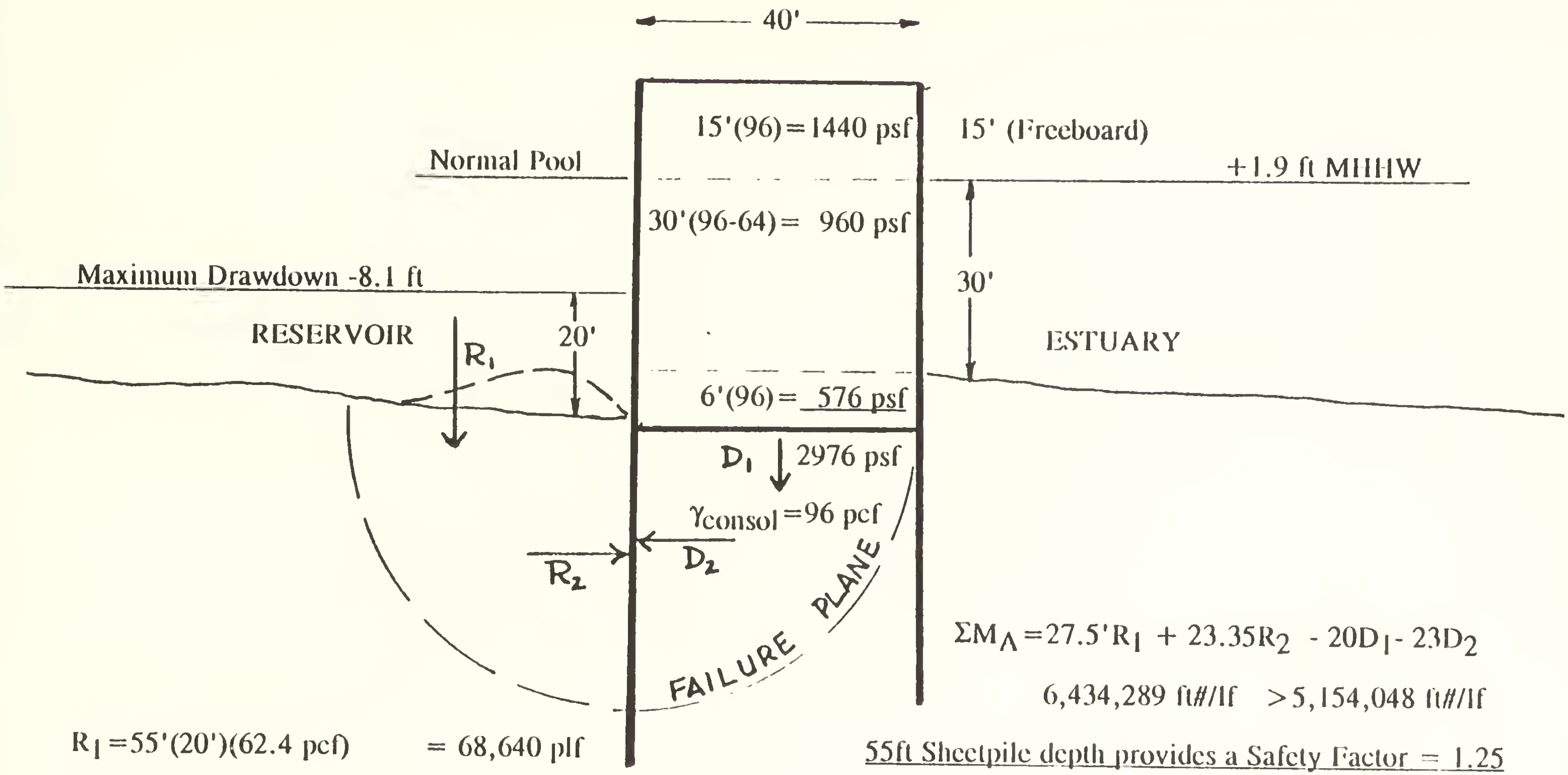
Using data gathered by (Lum, 1975):

H	-- Sample height, .009 ft
C_c	-- Compression Index, 127
e_0	-- Initial void ratio, 3.52
$\bar{p}_0$	-- Unconsolidated compressive strength, 1920 psf
Δp	-- Consolidated compressive strength, 3587 psf

a settlement of about 6 feet is predicted. As the structure settles, a gradual heave would normally occur on either side. This type of failure can be constrained by driving the sheet pile across the failure plane, to a depth sufficient enough to resist the lateral forces along this plane. By performing a mass balance of the forces acting on the failure plane during maximum drawdown, a sheetpile depth of at least 55' is suggested (Figure 5-2). This depth could also be reduced by adding surcharge material alongside the base and placing a blanket of uniform sand between the clay bottom and the hydraulic fill.

Seepage under the dam foundation is also a concern because high gradients could cause erosion in the porous clay sediments that would cause instability in this narrow structure. Figure 5-3 shows a flownet for the proposed structure using Cedergren's construction techniques (Cedergren,1989). Based on this construction, it can be seen that the seepage gradient and volume can probably be controlled at satisfactory levels.

This analysis is not intended to provide simple solutions to a complex geotechnical problem. Rather it merely demonstrates that this approach is within the realm of current engineering technology. It also emphasizes the need for additional research and investigation to further assess the feasibility of this project.



$\Sigma M_A = 27.5'R_1 + 23.35R_2 - 20D_1 - 23D_2$

6,434,289 ft#/lf > 5,154,048 ft#/lf

55ft Sheetpile depth provides a Safety Factor = 1.25

$R_1 = 55'(20')(62.4\ \text{pcf}) \quad = 68,640\ \text{plf}$

$R_2 = \pi(55')^2/4(82.6\ \text{pcf}) \quad = 194,719\ \text{plf}$

$D_1 = 2976\ \text{psf}(40') \quad = 119,040\ \text{plf}$

$D_2 = \pi(40')^2/4(96\ \text{pcf}) \quad = 120,576\ \text{plf}$

FIGURE 5-2 MASS BALANCE at FAILURE PLANE

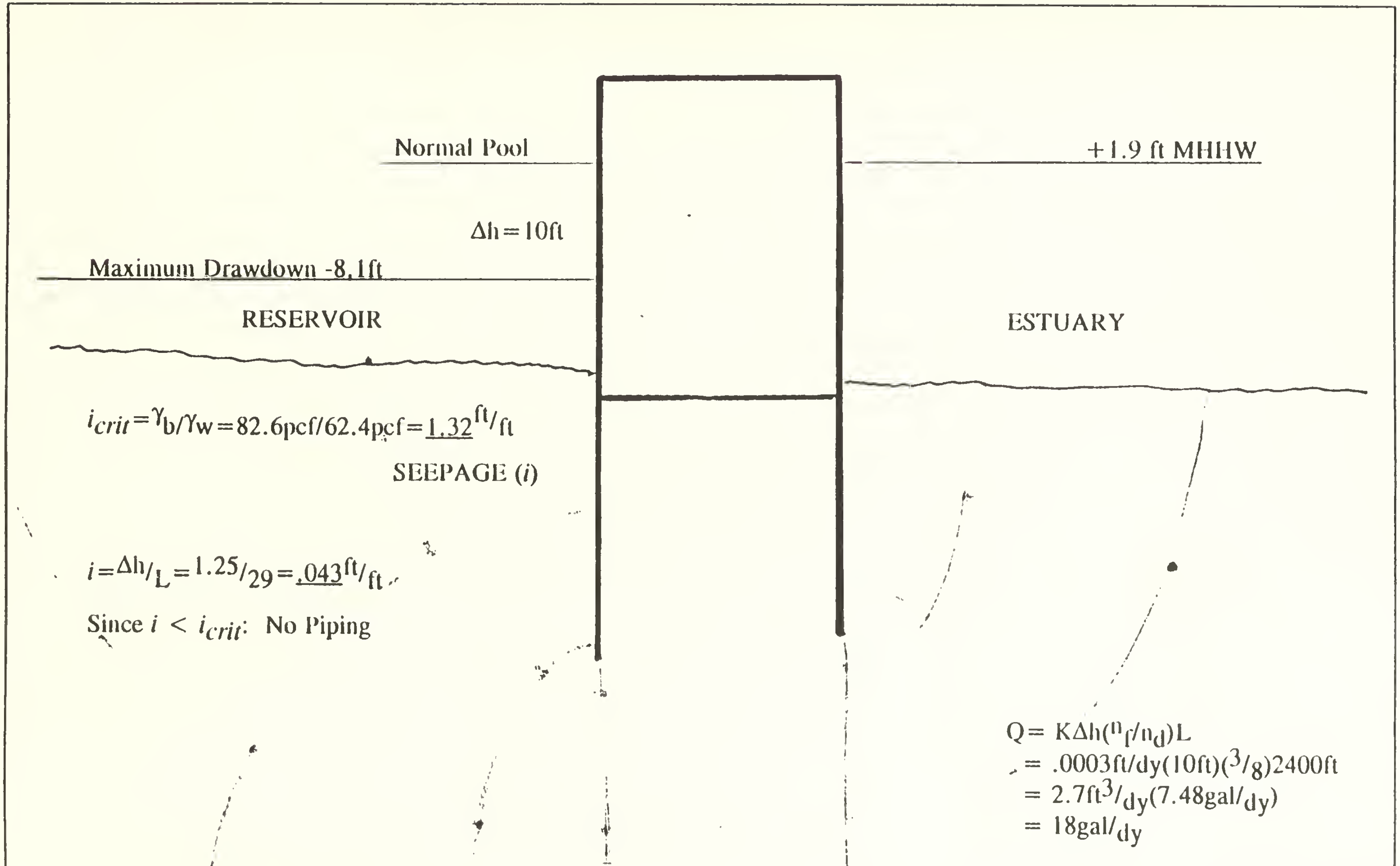


FIGURE 5-3

FLOW NET across DAM BASE

ROADWAY

The pavement design should be capable of withstanding heavy tractor-trailer truck traffic and of adequate width to allow two-way flow in the event of a breakdown. For this preliminary plan costs will be developed for two 12' travel lanes with 8' shoulders using 12" portland cement concrete pavement with a 12" thick, $1^{1}/_{2}$" aggregate base course. This would be constructed in conjunction with 40"x12" grade beams spaced at 20 foot intervals to form a cap for the dam that will provide lateral stabilization. Precast, single faced concrete median barriers will be placed along the edge of the roadbed to prevent vehicles or workers from falling of the dam.

SPILLWAY

Since the potential for death or property damage from dam failure or flooding is small, it is prudent to design the dam and spillway to accommodate a 100 year, 24 hour storm (Viessman, 1989). The forty year record of flow data is sufficient to extrapolate predictions for this 100 year storm. FEMA estimates the peak discharge of a 100 year, 24 hour storm at 26,400 cfs for Waikele Stream and 8,030 cfs for Honouliuli Stream (FEMA, 1990). Although some savings could be realized by routing these storm flows through the reservoir, we will assume a peak discharge of 34,430 cfs. Many design alternatives exist but for the purpose of this conceptual plan the Hazen -Williams formula was used:

$$Q = .432CD^{2.63}S^{.52} \qquad \text{(Eqtn 5--1)}$$

Assuming: C -- Coefficient of Roughness = 100
D -- Pipe Diameter = 4 feet
S -- Pipe Slope = .1

to find that 70, 48" class 3, reinforced concrete pipe culverts spaced at 35 foot intervals along the length of the dam will handle this flow. This method is advantageous because it would also improve the lateral stability of the structure.

INTAKE STRUCTURE

The same basic structure proposed by the BWS (Chang, 1973) will be used in this plan. It provides a 48" pipeline from the intake crib to the wet well and then on to the treatment facility. A pumping station with 40 mgd capacity will be constructed above the wet well at ground level.

WETLAND HABITAT

Cost effective potable treatment is obviously dependent on obtaining the best raw water quality possible. The natural purification process of tropical lakes is enhanced by water hyacinth (Brown, 1979) and the value of these plants for treated sewage has already been demonstrated (Okita, 1991). The Deltaic deposits at the mouth of Waikele and Honouliuli Streams are the best borrow areas for the dredged fill (Figure 5-4) because of higher compressive stress (Turner, 1975). Dredging here would create natural sedimentation basins and reduce unsightly mud flats during periods of reservoir drawdown. As dredging progresses it make sense to create wetland habitat for endangered water fowl by planting water hyacinth and california grass around the borrow areas. This would improve raw water quality in the impoundment, reduce the impact of high storm turbidity on the reservoir, and screen remaining mud flats from public view. The proliferation of water fowl within the wetland would also help control mosquito propagation which was sited as a concern in previous studies (Okita, 1991 and Gee, 1985). Excessive land costs which make this natural purification process uneconomical would be avoided because this government land is already restricted from public use.

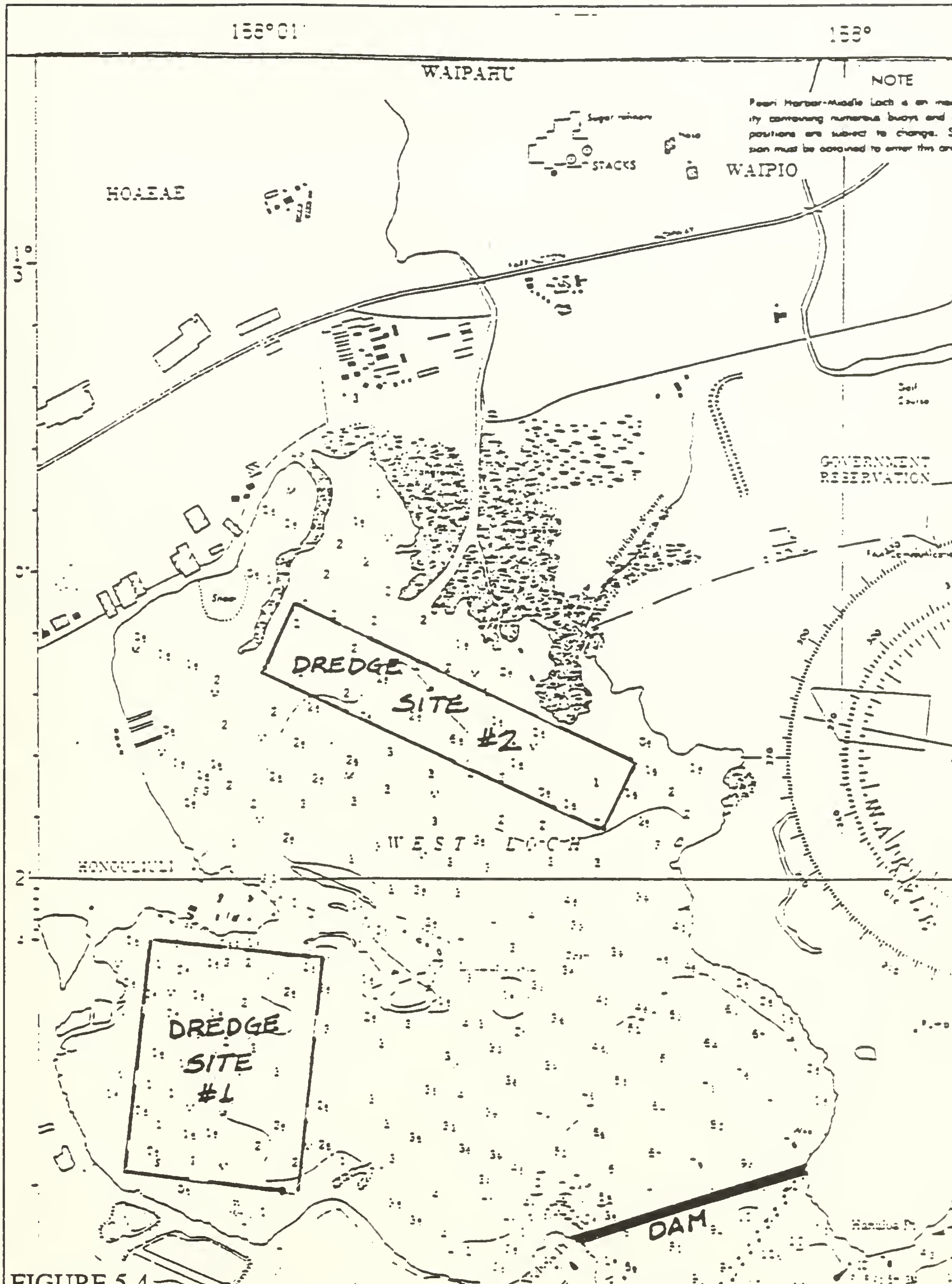


FIGURE 5-4

Source: (DMA Chart No.19366, 1991)

DREDGING & WETLAND SITES

TREATMENT PLANT

A large range of treatment options are available depending on the initial water quality. Table 5-1 synopsizes treatment reductions required for critical water quality parameters.

TABLE 5-1. West Loch Treatment Requirements

Parameter	Units	Waikele Stream	Impoundment	Treatment Std / Goal	Reduction Required
COLIFORM	col/100ml	6136	600-60	0 (.05)	99.99-99.9%
TURBIDITY	NTU	6.25	380-3.25	0.5 / 0.1	99.98 / 97%
TDS	mg/l	227	225	500[a] / 200	0 / 11%
MANGANESE	ug/l	52.41	52	50[a]/ 10	4 / 81%
LEAD	ug/l	3	.3	15/5	0
HARDNESS	mg/l	57.76	58	80[b]	0
IRON	ug/l	50.83	51	300[a]/ <50	0 / 2%
ALUMINUM	ug/l	19.95	20	<50[b]	0
CHLORIDES	mg/l	61.14	62	250[a]	0

[a] Secondary Maximum Contaminant Limit, attainment not mandatory
[b] AWWA treatment goal. No NPDWS established.

Attaining the "no detectable coliform" goal may present the most persistent water treatment challenge in West Loch. The surface water treatment rule (SWTR) requires that no more than 5% of all monthly samples test positive for total coliform. Based on industry research, convention rapid sand filtration is the best technology for surface water treatment. Conventional treatment consists of coagulation, flocculation, sedimentation, rapid granular filtration, and disinfection (Leland, 1986). Coagulation / Filtration provides removal rates of >99.99% for coliforms, 90-97 percent for Turbidity and 50% for iron and manganese (Dyksen, 1986). A further 4-6 log reduction in coliforms is expected from disinfection (Geldreich,1980). This should achieve the primary drinking water standards (NPDWS) as long as periodic filtration "breakthroughs" are controlled. higher solids and viral removal can be achieved by using a dual media filter (Murphy, 1989). By adding aeration to the pretreatment, TDS reductions of 16% have been achieved (Jones, 1989) and higher removal rates can be

expected for manganese. Disinfection using chlorine dioxide may be advantageous in this situation because it provides adequate residual disinfection without producing trihalomethanes. It also results in higher rates of iron and manganese removal (Clark, 1990).

Based on this information it appears that all the NPDWS can be achieved except turbidity which may be exceeded during severe storms. Since the SWTR allows this limit to be exceeded in 5% of all monthly samples, these events will pose no treatment problem. These treatment requirements only provide a rough approximation to appraise the processes that may be needed. Actual treatment design should not be attempted until after the reservoir has been filled and chloride concentrations have stabilized. Only then can reliable sampling be conducted to establish specific treatment requirements.

Plant size is another important consideration. Even though the reservoir will support a 25 mgd supply, construction of a treatment facility with larger capacity is prudent for several reasons. First a large economy of scale is prevalent in water treatment facilities. In 1978 the EPA estimated the cost of a 5 mgd plant at $2,364,000 and a 40 mgd facility at only $10,334,390. Secondly, larger treatment facilities allow the capture of more runoff during the wet season. This allows reduced pumping from groundwater sources which in turn preserves the aquifer's sustainable yield for drought conditions when reservoir levels may reduce the availability of the surface supply. Larger plant capacity also increases reservoir management options. Finally, it will allow for future expansion if additional surface runoff is diverted to the impoundment (BWS, 1978). Based on this rationale, 40 mgd water treatment plant is recommended.

Distribution System

Since reservoir water quality improves with detention time, it is logical to locate the plant intake structure as near to the dam as possible. This intake should be located

near the bottom to promote full circulation within the reservoir but not so low that sedimentation will interfere with its operation. By locating the intake structure near the west end of the dam structure and siting treatment facilities on government property just north of the main entrance to NAVMAG West Loch costly distribution facilities could be avoided. This site would probably require construction of protective earth berms to satisfy safety requirements for construction within the ESQD. If DOD approval is granted for use of this site the Navy would have to be compensated in some way for use of this land.

Now that we have a design concept it is time to determine how much it could cost. That will be the subject of the next chapter.

REFERENCES

_________, August 26-28, 1968. Placement and Improvement of Soil to Support Structures. A Specialty Conference, Soil Mechanics Foundations Division, American Society of Civil Engineers, Cambridge, Massachusetts.

Board of Water Supply (BWS) , July 20, 1979. *West Loch Impoundment Utilizing Water From Waikele and Waiawa Stream.* City and County of Honolulu, Hawai'i.

Cedergren, H.R., 1989. Seepage, Drainage, and Flow Nets. 3rd edition, John Wiley & Sons, Inc. New York, New York.

Chang, J.Y.C., 1973. *"A Study of West Loch Impoundment."* Unpublished Report. Division of Planning, Resources and Research, Board of Water Supply, City and County of Honolulu, Hawai'i.

Clark, R.M.., 1990. *"Chapter 5: Water Supply",* Standard Handbook of Environmental Engineering. R.A. Corbitt, editor, McGraw-Hill, Inc., St. Louis, MO.

Dyksen, J.E., June 22-26,1986. *" The Capabilities of Standard Water Treatment Processes to Meet the Revised Drinking Water Regulations".* 1986 Annual Conference Proceedings, American Water Works Association, Denver, CO.

Federal Emergency Management Agency (FEMA), September 28, 1990. *"Flood Insurance Study, City and County of Honolulu, Hawai'i".*

Fok , Y. -S. and Murabayashi, E.T. September, 1991. *"Impoundment of Stream Flow in West Loch, Pearl Harbor, Oahu, Hawai'i: A Feasibility Study"*. Technical Report #192. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Gee, H.K., Murabayashi, E.T., Young, R.F, September 1985. *" Wastewater Irrigation for Alfalfa, Guinea Grass, and Papaya Production in Hawai'i"*. Technical Report #170. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Jones, G. N., Bergman, R.A. and Pickard, D., June 18-22, 1989. *"Recovery of Municipal Wastewater Using Advanced Treatment Technologies at Tampa, Florida"*. 1989 Annual Conference Proceedings, American Water Works Association, Los Angeles, California.

Kazi, A. and Moum, J., August 1-2,1973. *"Effect of Leaching on the Fabric of Normally Consolidated Marine Clays"*. Proceedings of the International Symposium on Soil Structure, Gothenburg 1973. Swedish Geotechnical Society, Stockholm, Sweden.

Leland, D.E., June 18-22, 1989. *"Understanding the Surface Water Treatment Rule"*. 1989 Annual Conference Proceedings, American Water Works Association, Los Angeles, California.

Le Mehaute, B., 1970. *"Explosion Generated Water Waves"*. 8th Symposium on Naval Hydrodynamics, Pasadena, California

Lum, W. Associates, Inc., May 12, 1975. *"Pearl City Pump Station Modification and New Force Main Soil Exploration Report"*. Park Engineering, Honolulu, Hawai'i.

Munro, K., August, 1981. *"The Subsurface Geology of Pearl Harbor with Engineering Application"*. Graduate Thesis for Master of Science in Geology and Geophysics, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Murabayashi, E.T. and Fok , Y. -S. 1983. "Stream-water storage in the ocean by using an impermeable membrane". Technical Report #152. Water Resources Research Center, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Murphy, R.C., June 18-22, 1989. *"Impact of Water Quality Criteria on the Production, Distribution and Use of Reclaimed Water in An Urban Dual Distribution System"*. 1989 Annual Conference Proceedings, American Water Works Association, Los Angeles, California.

Okita, R.H., May 1991. *"Use of Water Hyacinth to Provide Secondary Treatment of Wastewater from the Honouliuli Sewage Treatment Plant"*, Graduate Thesis, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Terzaghi, K. and Peck, R.B., 1967. Soil Mechanics in Engineering Practice. John Wiley & Sons, Inc. New York, New York.

Turner, B.W., August, 1975. *"Mineral Distribution within the Sediments of Pearl Harbor"*. Graduate Thesis for Master of Science in Geology and Geophysics, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Viessman, W., Lewis, G.L. and Knapp, J.W., 1989. Introduction to Hydrology. Chapter 16, Hydrologic Design. Harper & Row, Publishers, New York, New York

Wang, Le Mehaute, B., 1987. *"Water Waves Generated by Subsurface Detonation in Very Shallow Water"*. Defense Nuclear Agency Report.

Wang, 1992. *"Explosion Generated Water Waves: Series Generalization and Calibration"*. Draft Defense Nuclear Agency Report.

Whitman, R.V. May 22, 1969. *"Hydraulic Fills to Support Structural Loads"*, Placement and Improvement of Soil to Support Structures. A Specialty Conference, Soil Mechanics Foundations Division, American Society of Civil Engineers, Cambridge, Massachusetts.

Yuen, G.A.L. and Associates, 1989. *"Groundwater Resources and Sustainable Yield, Ewa Plain Caprock Aquifer"*. Commission on Water Resources Management, Department of Land and Natural Resources, Honolulu, Hawai'i.

CHAPTER SIX
Cost Comparison

Now that we have identified facilities requirements and developed a conceptual plan it is time to estimate the project cost. Then we can determine the unit cost for potable water and compare it to unit costs of other treatment alternatives. The following project cost summary has been developed for the facilities requirements identified in Chapter 5. These costs have been estimated using Means Site Work Cost Data-1991, Means Heavy Construction Cost Data-1992 and the Engineering News Record Construction Cost Index (CCI). Some data from previous studies of this concept have been used after adjustment for inflation. Cost for data collection and preliminary design studies presume that much of the initial work can be accomplished through graduate study grants. This will minimize costs until enough evidence is available to clearly warrant full scale project development. Although a half a million dollars seems excessive for environmental impact assessment, growing resistance to water resources projects in general (Work, 1989) and the volatile history of recent public works projects in Hawai'i suggest that thorough documentation and extensive public involvement will be necessary. Overhead includes both field and home office administrative costs for a large construction company since a high level of construction expertise and demonstrated performance will be required for a project of this magnitude. Profit is based on the assumption that a governmental entity will assume most of the risk by preparing the design specifications for a competitively bid, fixed price contract. It must be emphasized that this estimate is based on a single planning concept and not necessarily the most cost effective design. As more technical data is gathered it is expected that cost will decrease because this estimate is intentionally very conservative and a 25% contingency is provided for this preliminary planning.

COST SUMMARY

DAM		**8,795,300**	
Sheet Piling	7,110,300		
Dredging	802,600		
Dewatering / Wellpoints	377,500		
Hydrostatic Membrane	504,900		
SPILLWAY		**171,640**	
ROADWAY		**758,600**	
INTAKE STRUCTURE[40]		**960,000**	
IMPOUNDMENT CONSTRUCTION COSTS			**$10,685,500**
WETLAND HABITAT[41]		**350,000**	
Dredging Habitat	0[42]		
Water Hyacinth	200,000		
Plant Natural Ground Covers	150,000		
TREATMENT PLANT[43]		**12,742,050**	
Chemical Feed Systems	225,800		
Rapid Mix	70,750		
Flocculation	715,300		
Clarifiers	3,595,700		
Filtration	4,059,100		
Disinfection	224,000		
Clearwell Storage	1,456,300		
Pumping Station	664,000		
Sludge Handling / Disposal	783,700		
Admin, Lab, Maint. Bldgs	345,900		
Sitework / Infrastructure	601,500		
WATER TREATMENT CONSTRUCTION COSTS			**$13,092,000**
TOTAL CONSTRUCTION PRICE			**$23,777,500**
OVERHEAD (14%) & PROFIT (6%)			**4,755,500**
TOTAL CONSTRUCTION COST			**$28,533,000**
CONTINGENCY (25 %)			**7,133,300**
EIS AND DATA COLLECTION (2%)			**570,700**
DESIGN STUDIES (6%)			**1,712,000**
PROJECT FUNDING REQUIREMENTS			**$37,949,000**

40 Based on BWS estimates adjusted by CCI.

41 Based on professional judgment from past experience with other natural resource projects.

42 Accomplished by specification with dam dredging.

43 See EPA-600/2-79-162 a&b. Adjusted by using CCI.

Amortizing the project cost over the life of the improvements, assuming the current discount rate of 6% will rise to 7% before contract award and adjusting estimated operating expenses for a 40 mgd facility (Gumerman, 1979) for inflation using the consumer price index (CPI) and an average production of 24.47 mgd, it can be determined that:

ANNUAL CAPITAL IMPROVEMENT COST (50 year Lifecycle; 7% Discount Rate)	\$ 2,750,000
OPERATING COST	<u>\$ 7,489,700</u>
PRODUCTION COST	\$10,239,700

Unit Cost $10,239,700 ÷ 24.47 mgd x 365 days/yr = **$1.15 /1000 gallons**

COST COMPARISON

Unit cost of potable water produced from surface water compares favorably with current the BWS water rate of $1.34/1000 gal since EPA operating costs include pumping costs for finished water (Gumerman, 1979). It is also important to note that comparison with operating costs for the Howard Bend Treatment Plant which treats raw water from the Missouri River in St. Louis, indicate that the EPA operating cost estimate for a 40 mgd Plant may be highly inflated. Treatment, pumping and power costs for 1992 at this facility were only $.264 /1000 gallon based on an average production of 42 mgd. Total operating cost at this plant were only $4,229,579 during this period (Visintainer, 1993). If this is the case surface impoundment compares even more favorably than other alternatives that have previously been considered. Using the operating costs from Howard Bend plant to determine the low range of the possible production cost yields:

ANNUAL CAPITAL IMPROVEMENT COST	$ 2,750,000
OPERATING COST	$ 4,229,600
PRODUCTION COST	$ 6,979,600

Unit Cost $6,979,600 ÷ 24.47 mgd x 365 days/yr = **$0.78 /1000 gallons**

Table 6-1 compares the unit production cost for several potable water options that have been considered over the years. All cost are adjusted to 1992 prices.

Table 6-1. Unit Cost for Potable Production Alternatives.

CURRENT BWS RATE	$1.34 / 1000 gallons
CURRENT U.S. NAVY RATE[a]	$1.04 / 1000 gallons
CURRENT U.S. NAVY COST[a]	$0.84 / 1000 gallons
SURFACE IMPOUNDMENT 25 mgd (9,125 mgal/yr)	$0.78 - 1.15 / 1000 gallons
GROUNDWATER RECHARGE[b]	
Diversion Dam (1600 mgal/yr)	$1.03 / 1000 gallons
Storage Dam (2100 mgal/yr)	$1.90 / 1000 gallons
DESALINATION[c]	
Prototype (73 mgal /yr)	$16.14 / 1000 gallons
1 mgd (365 mgal/yr)	$3.77 / 1000 gallons
10 mgd (3,650 mgal/yr)	$0.72 / 1000 gallons

[a] See (PWC, 1992)
[b] See (R.M. Towill, 1978)
[c] See (Moncur, 1992)

Comparing U.S. Navy cost with actual billing rate reveals that overhead and capital improvements costs increase production cost about 20%. Assuming that BWS

rates are determined similarly, a production cost of $1.07 can be calculated. This makes surface impoundment a very attractive alternative potable supply even without allocating construction costs for residual benefits. Impoundment provides almost six times the capacity of the most cost effective groundwater recharge option at comparable cost. It is also far more cost effective than current local desalination efforts and may be competitive with large desalination facilities with roughly half the treatment capacity. Although its difficult to draw definitive conclusions at this early stage, it is clear that treatment of impounded surface water deserves further consideration as Oahu's future potable supply.

REFERENCES

Gumerman, R.C., Culp, R.L. and Hansen, S.P., August 1979. *"Estimating Water Treatment Costs"*. Environmental Protection Agency publication EPA-600/2-79-162 a&b.

Moncur, James, Gee, H. and Gogineni, R., September 3, 1992. "The Ewa Demonstration Desalination Experiment: A Preliminary Report". Water Resources Research Center Seminar, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Public Works Center (PWC), Pearl Harbor, 1992. *"Potable Water historical Costs"*. Utilities Department, Code 600 Computer File: UTILHIST.WK1, U.S. Navy, Pearl Harbor, Hawai'i.

R.M. Towill Corporation, September, 1978. *"Feasibility Study: Surface Water Impoundment / Recharge, Pearl Harbor Basin, Oahu, Hawai'i"*. U.S. Army Corps of Engineers, Pacific Ocean Division, Fort Shafter, Hawai'i.

Visintainer, D.A., January 14, 1993. *Request for Financial And Operating Data*. Official Letter, Water Division, Department of Public Utilities, City of St. Louis, MO

Work, S.W., Miller, W.H. and Pokorney, E.E., June18-22, 1989 *"Reservoirs--The Endangered Species"*. 1989 Annual Conference Proceedings, American Water Works Association, Los Angeles, California.

<u>CHAPTER SEVEN</u>
Implementation Plan

Investigation of the potential water shortfalls on Oahu strongly supports a joint venture solution that promotes full participation of federal, state and local government as well as private developers, landowners and the general public. With the cooperative efforts of all interested parties, it appears that a mutually beneficial solution can be accomplished within the framework of the existing regulatory structure. Before developing a plan of action a summary of the current situation is in order.

SYNOPSIS

1) The Clean Water Act (CWA), has resulted in important improvements to the water quality of the Pearl Harbor estuary. In spite of significant pollution abatement action, Pearl Harbor still exceeds State water quality standards as a result of unregulated non- point sources (DOH, 1990). A freshwater impoundment located within the confines of the West Loch of Pearl Harbor would serve to control the distribution of nonpoint source pollutants from runoff of Waikele, Kipapa, Waikakalaua, Kapakahi and Honouliuli Streams.

2) The construction of this freshwater impoundment could provide an ideal demonstration project for new and innovative methods of controlling accumulated pollution from non-point sources. § 1252 of the Clean Water Act could provide a source of significant funding for this project:

3) Substantial data is available to support claims of continuing water quality improvement but is not adequate to provide a quantitative evaluation (Grovhoug, 1992). Resumption of limited sampling on a bi-monthly basis at the seventeen stations recommended in the baseline study, in conjunction with USGS stream quality monitoring, could provide valuable information to assess the impacts of non-point

source pollutants. This program would also provide necessary flow and water quality data for further studies of impoundment effects as well as supply conclusive evidence of water quality trends.

4) Sediment contaminants do not adversely impact the quality of the water column and seem to have minimal impact on bioassay test organisms (Morris and Youngberg, 1972 and Grovhoug, 1992).

5) Sediment contamination within West Loch is lower than most US harbors and appears to have improved as a result of point source control and maintenance dredging (NEESA, 1983). It is therefore not likely that funds could be obtained from the CERCLA Superfund or the DOD Installation Restoration Program to pay for dam construction.

6) The fate of sediment contaminates should be evaluated to ensure that freshwater impoundment will not increase concentrations of toxic inorganic substances.

7) High levels of coliforms, turbidity, total dissolved solids, and manganese, will require treatment if water from Waikele Stream is to be used for potable supply.

8) The above noted stream quality parameters, as well as chloride, lead , hardness, iron, and aluminum , should be evaluated to estimate their fate in a freshwater impoundment.

9) The concentrations of stream quality parameters that exceed SDWA standards are not too high to preclude effective treatment.

10) A limited crossection dam, constructed with hydraulically placed dredge spoils, may provide an economical method of impoundment. This structure can reduce construction cost and minimize excavation requirements thereby reducing the likelihood of disturbing archeological sites. This method should avoid conflict with the ship turning basin that is critical to naval operations at the NAVMAG.

11) Conflict with the explosive safety zone of the NAVMAG cannot be avoided so an early assessment of potential damage to the dam structure must be conducted to ensure that potential risks are within reasonable levels as determined by the State and the DOD.

12) Conventional treatment of impounded freshwater can compete economically with desalination as an alternative potable water supply for Oahu. If project costs are distributed among all beneficiaries further reductions can be realized in the capital improvement cost that may bring productions costs in line with the current water rate structure.

13) An EIS is necessary to determine if significant impacts are likely. Early public involvement during the scoping phase will provide valuable indicators of public acceptance and support for this concept.. It will also further delineate potential benefits that can be derived from this project. This will allow a more equitable distribution of planning and research costs among those organizations that participate in development

14) The construction of any dam across navigable waters requires Congressional consent and the approval of the plans and issuance of "Section 404" permits by the Corps of Engineers.

15) Biennially the Corps submits water resource projects that offer a wide range of benefits to the community, for federal funding through the Water Resources Development Act (_____, 1991). This seems to be the best alternative for full funding of this project.

POTENTIAL BENEFITS

If project costs must be distributed between beneficiaries, what are the potential benefits? The following list represents only a preliminary review. No attempt has been made at this early stage of planning to quantify these benefits.

1) Oahu will be provided with an new source of potable water that complements existing groundwater supplies and can support future economic development and population growth without causing water rates to increase.

2) Constraints on development in the Ewa Plain can be eased allowing projects to proceed without fear of costly delays resulting from inadequate water allocations. Sugar production can continue without threat of further cuts in existing allocations.

3) Sedimentation of West Loch will be controlled thereby improving estuary water quality and reducing dredging frequency in ship channels.

4) Valuable data will be collected that can correlate the effects of soil erosion and non-point source pollution on water quality. The results of past point source pollution abatement efforts can be quantified. This information may allow the expenditure of hundreds of millions of dollars on sewage collection systems rather than costly secondary treatment plants that would only marginally improve water quality. The data may also be useful in establishing new controls to further improve water quality throughout the Hawaiian islands.

5) New wetland habitat will be created and existing habitat will be enhanced. Additional critical habitat will be available for endangered waterfowl.

6) The use of an earthen dam will have the residual benefit of providing valuable access to Waipio Peninsula. This could allow consolidation of naval activities that would free land for development of military housing. Additional water allocations would be available for military housing on Ford Island. An alternative water source will be available in the event that the Waiawa Shaft would become contaminated.

PLAN OF ACTION

1) Submit this proposal to The Pearl Harbor Estuary Program Interagency Committee for review and comment by all affected parties. Invite the SCLDF to represent the "public interest" on this steering committee.

2) Identify and quantify additional benefits and potential adverse impacts. Revise the proposal under the guidance of the Committee to mitigate impacts if possible.

3) Develop a plan to gather data and conduct necessary research to confirm feasibility (Figure 7-1). Invite public comment on the proposal prior to initiating further research.

4) Initiate data collection and research using Navy fully-funded postgraduate students from the University of Hawai'i.

5) Agree on a funding allocation plan that distributes research, design and construction costs equitably between the beneficiaries.

6) Begin preparation of grant proposals to support research design and demonstration programs.

7) Review progress and reassess feasibility twice each year until sufficient data is available to make a final determination on the merits of the proposal.

Data Collection and R&D Requirements

- Resume limited sampling on a bi-monthly basis at the seventeen stations recommended in the NCEL baseline study, in conjunction with USGS stream quality monitoring.

- Assess potential for damage to the dam structure from explosion within the ESQD

- Evaluate the fate of sediment contaminates to ensure that impoundment will not increase concentrations of toxic inorganic substances.

- Conduct geotechnical studies to ensure technical and environmental feasibility of using a limited crossection dam constructed by hydraulic placement of dredged materials.

- Prepare an EIS to determine if significant impacts are likely

FIGURE 7-1

REFERENCES

_____, January 1991. "New Waterway's Bill Signed by President", World Dredging Mining and Construction, Vol. 27(1).

Department of Health (DOH), January 1990. *"Hawaii's Assessment of Non-point Source Pollution Water Quality Problems"*, State of Hawai'i

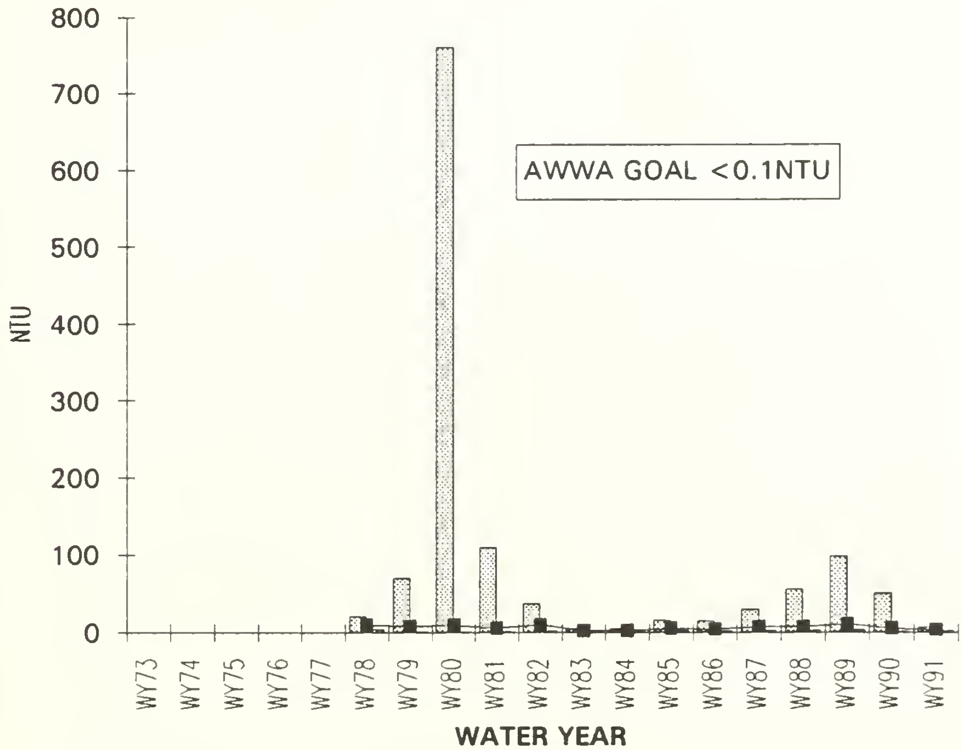
Grovhoug, J.G., January 1992. *"Pearl Harbor Environmental Site Investigation: An Evaluation of Potential Sediment Contamination Effects".* Marine Environmental Support Office, Hawai'i Lab, Naval Command, Control and Ocean Surveillance Center, Kailua Hawai'i

Morris, D.E. and Youngberg, A.D., April 1972. *Methods of Collection and Reporting of Sediment Samples from Pearl Harbor. EPDB 73-001.* Environmental Protection Data Base Office, Pearl Harbor Division, Naval Civil Engineering Laboratory, Port Hueneme, California

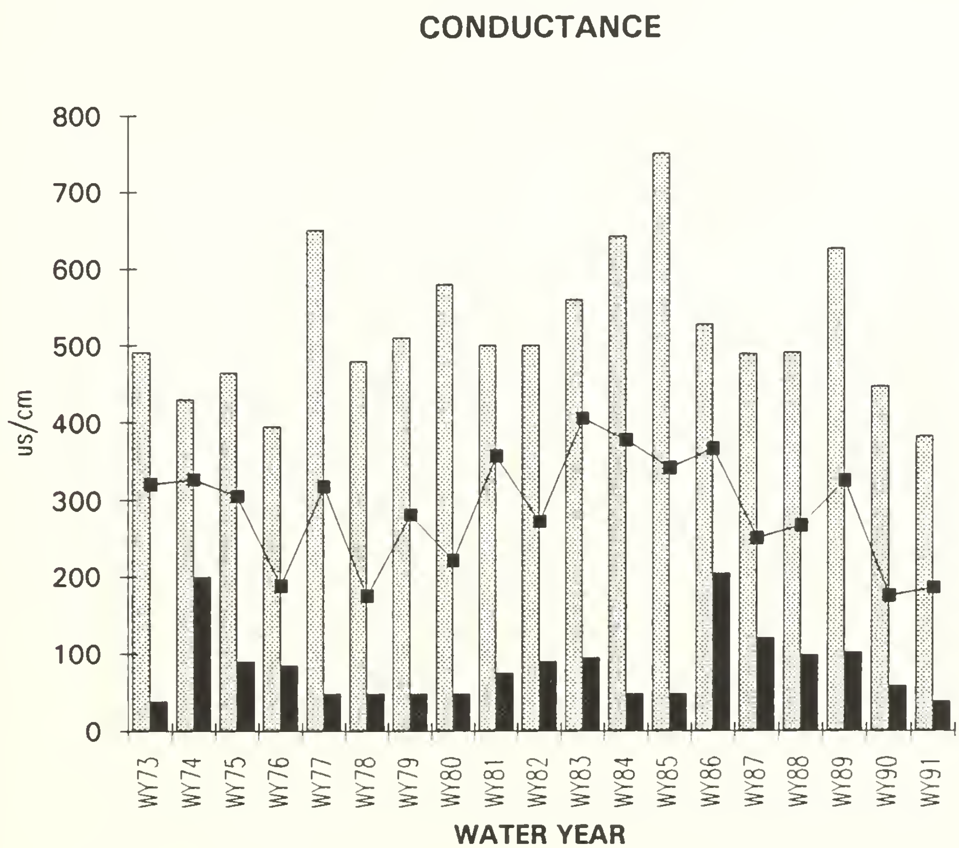
Naval Energy and Environmental Support Activity (NEESA), October 1983. *"Initial Assessment Study of Pearl Harbor Naval Base, Oahu, Hawai'i".* NEESA Report 13-002. US Navy, Port. Hueneme, California

APPENDIX A

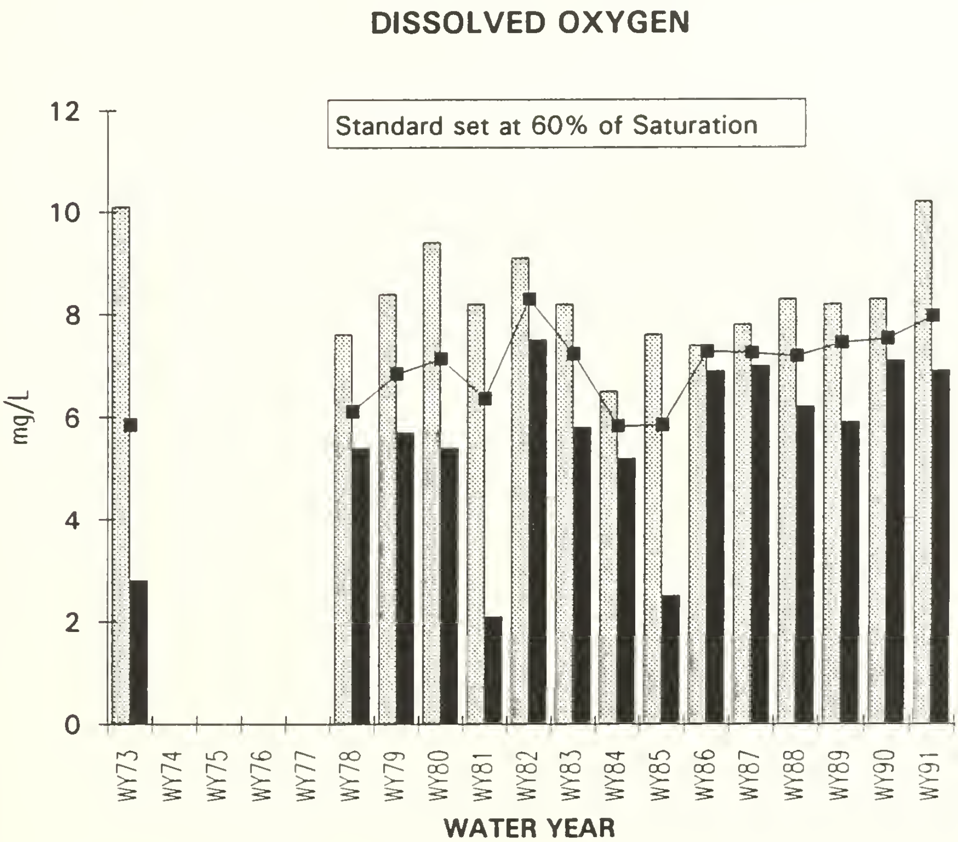
TURBIDITY



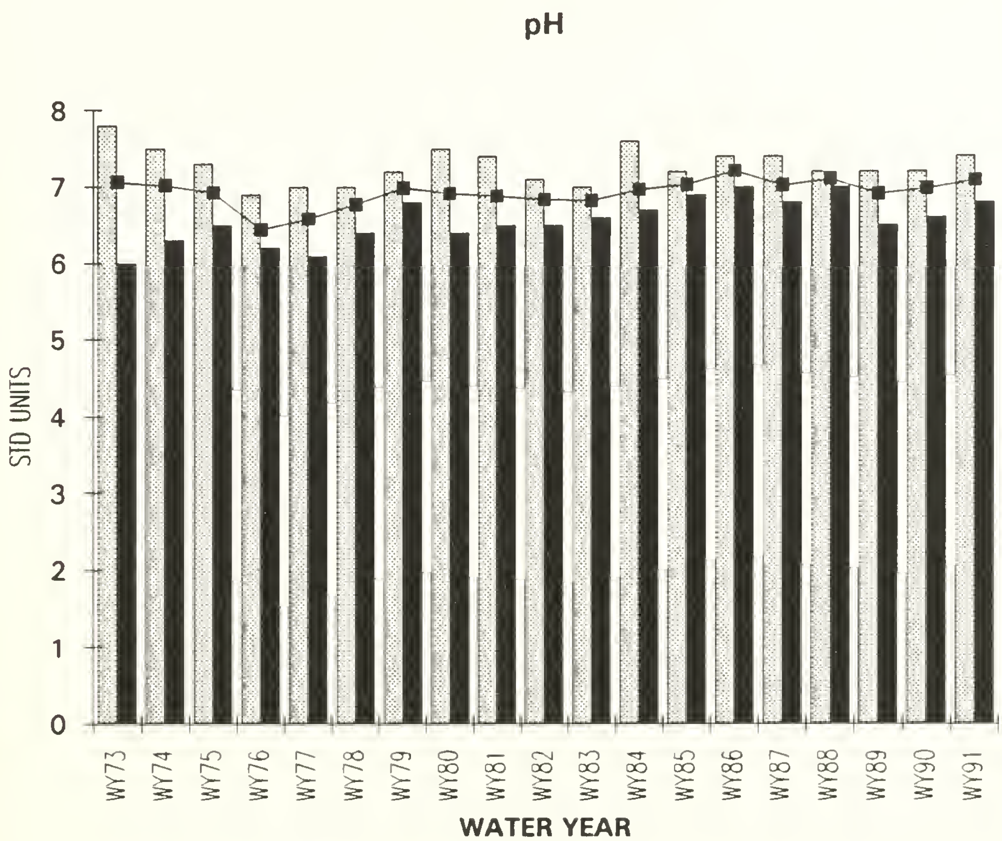
	MIN	MAX	MEAN
WY73	0	0	
WY74	0	0	
WY75	0	0	
WY76	0	0	
WY77	0	0	
WY78	4.4	21	9.409257623
WY79	1	70	7.817600564
WY80	0.9	760	9.335353452
WY81	1	110	5.649375966
WY82	1.6	37	9.52771053
WY83	1.1	4.99	2.281649817
WY84	1.4	5.2	2.300271376
WY85	2.5	16	5.013837771
WY86	1.4	15	3.845126086
WY87	1.9	30	7.086749
WY88	2.7	55	7.021385799
WY89	3.1	98	10.37642663
WY90	1.1	50	4.88063302
WY91	1.4	6.2	2.989738448
AVG			6.252508291



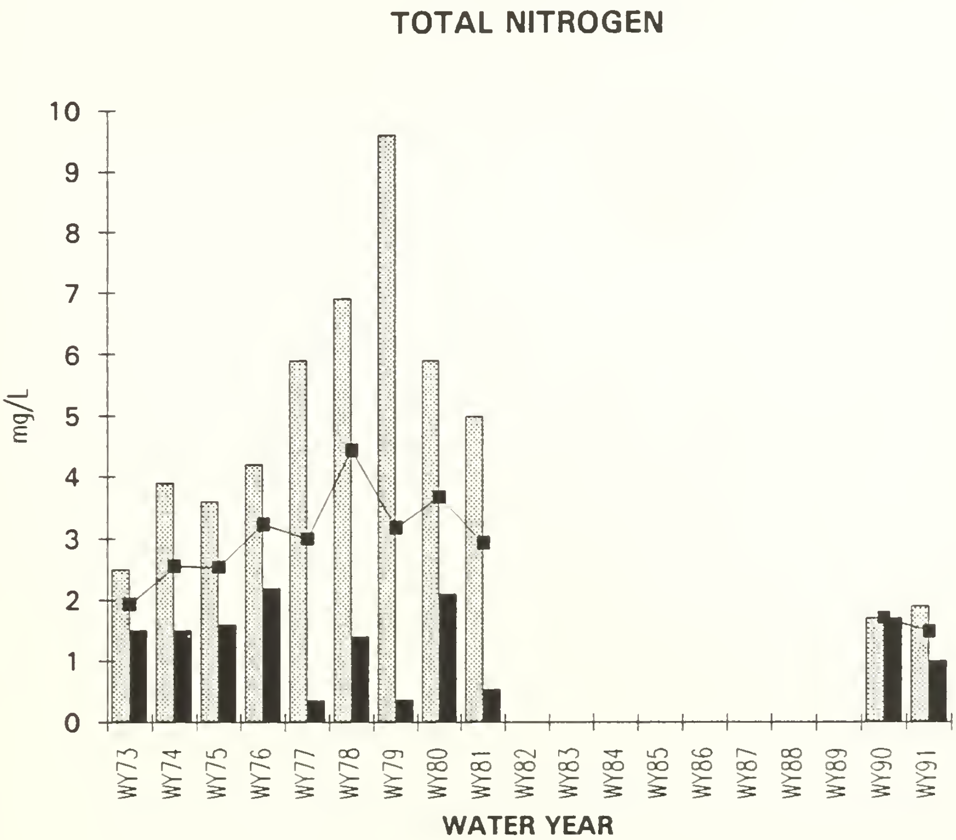
	MIN	MAX	MEAN
WY73	39	491	320.6564
WY74	200	430	326.6220841
WY75	90	465	305.4178139
WY76	85	395	188.748222
WY77	49	650	317.6512994
WY78	49	480	174.4626266
WY79	49	510	281.5793536
WY80	49	580	221.3674661
WY81	75	500	356.5534177
WY82	90	500	271.8615126
WY83	95	560	405.6004221
WY84	49	642	377.3680532
WY85	49	750	341.8115883
WY86	204	528	366.6708293
WY87	120	489	250.7024356
WY88	98	490	266.7353019
WY89	102	625	324.6031643
WY90	59	447	175.4518494
WY91	39	382	185.2811527
AVG			287.3234207



	MIN	MAX	MEAN
WY73	2.8	10.1	5.847224963
WY74	0	0	
WY75	0	0	
WY76	0	0	
WY77	0	0	
WY78	5.4	7.6	6.117971831
WY79	5.7	8.4	6.834354337
WY80	5.4	9.4	7.128518396
WY81	2.1	8.2	6.357600802
WY82	7.5	9.1	8.299248048
WY83	5.8	8.2	7.232132411
WY84	5.2	6.5	5.831092092
WY85	2.5	7.6	5.84084779
WY86	6.9	7.4	7.28566626
WY87	7	7.8	7.242788357
WY88	6.2	8.3	7.179129778
WY89	5.9	8.2	7.44064652
WY90	7.1	8.3	7.523214676
WY91	6.9	10.2	7.952319455
AVG			6.940850381

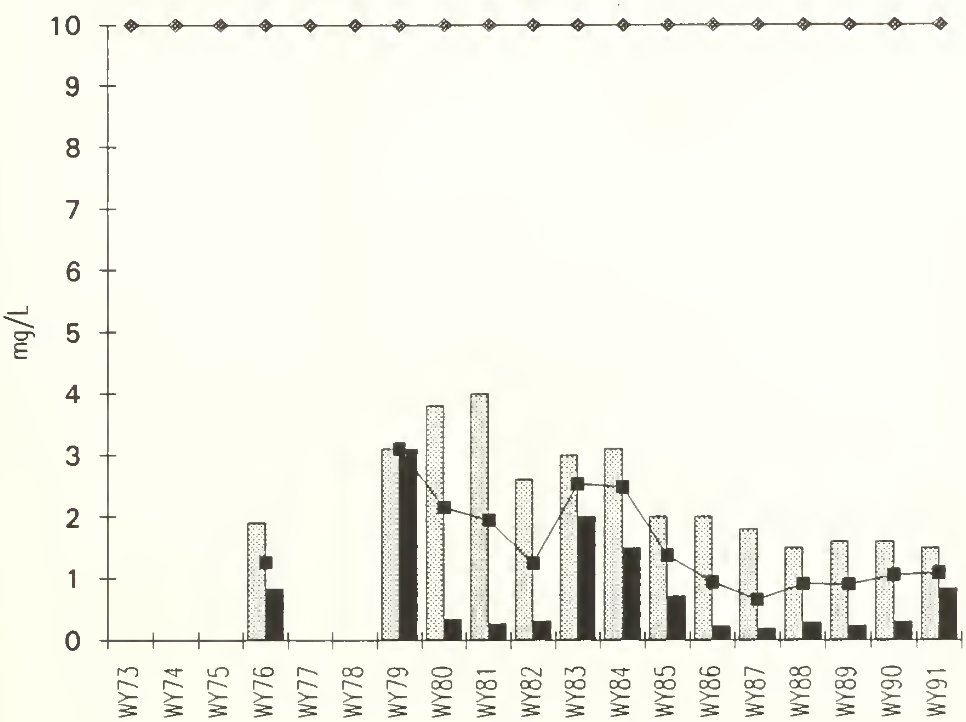


			MIN		MAX		MEAN
	WY73		6		7.8		7.06085
	WY74		6.3		7.5		7.01609
	WY75		6.5		7.3		6.92669
	WY76		6.2		6.9		6.44553
	WY77		6.1		7		6.5868
	WY78		6.4		7		6.77299
	WY79		6.8		7.2		6.99116
	WY80		6.4		7.5		6.91971
	WY81		6.5		7.4		6.88142
	WY82		6.5		7.1		6.83137
	WY83		6.6		7		6.824
	WY84		6.7		7.6		6.96655
	WY85		6.9		7.2		7.03239
	WY86		7		7.4		7.21121
	WY87		6.8		7.4		7.02137
	WY88		7		7.2		7.0993
	WY89		6.5		7.2		6.90995
	WY90		6.6		7.2		6.97984
	WY91		6.8		7.4		7.082
	AVG					AVG	6.92417

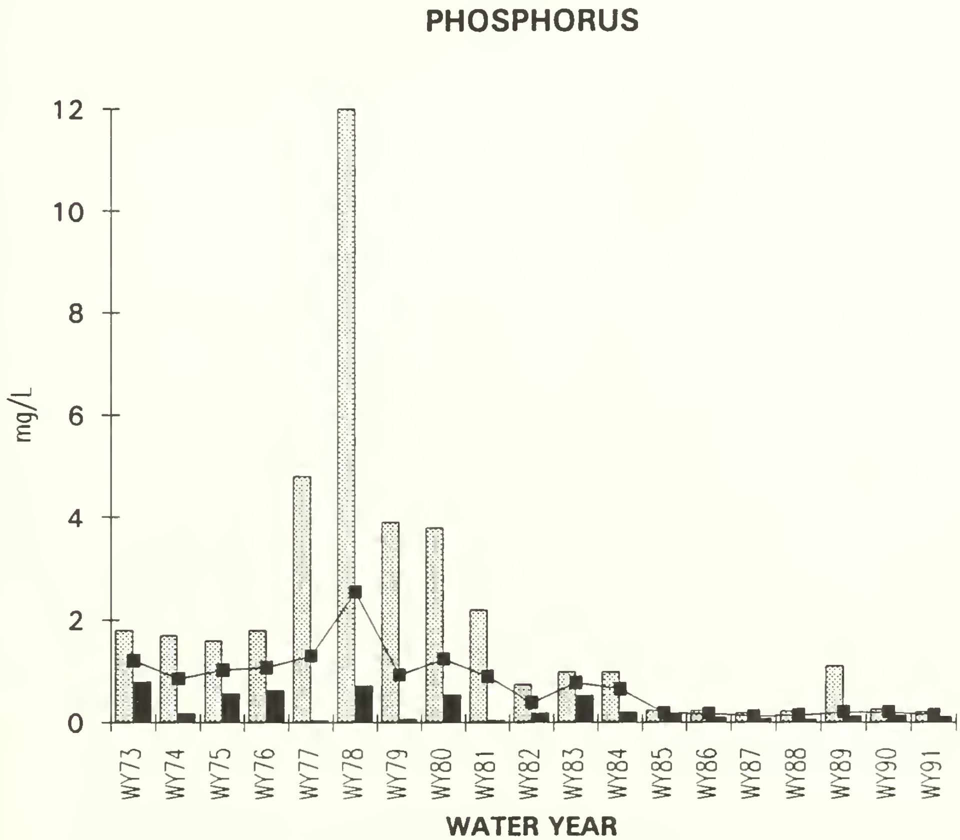


	MIN	MAX	MEAN
WY73	1.5	2.5	1.928927659
WY74	1.5	3.9	2.546312789
WY75	1.6	3.6	2.537727375
WY76	2.2	4.2	3.2332973
WY77	0.35	5.9	2.999140051
WY78	1.4	6.9	4.437240727
WY79	0.36	9.6	3.172037412
WY80	2.1	5.9	3.674505108
WY81	0.53	4.99	2.93209135
WY82	0	0	
WY83	0	0	
WY84	0	0	
WY85	0	0	
WY86	0	0	
WY87	0	0	
WY88	0	0	
WY89	0	0	
WY90	1.7	1.7	1.7
WY91	1	1.9	1.478965087
AVG			2.785476805

DISSOLVED NITRATE & NITRITE

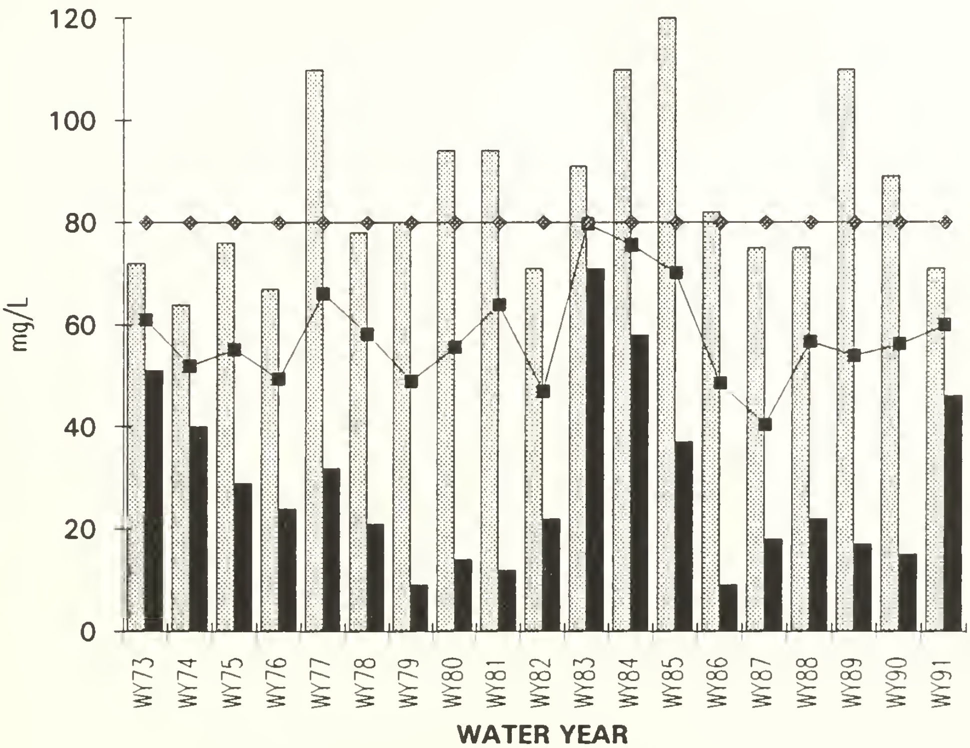


	MIN	MAX	MEAN	MCL
WY73	0	0		10
WY74	0	0		10
WY75	0	0		10
WY76	0.84	1.9	1.263328936	10
WY77	0	0		10
WY78	0	0		10
WY79	3.1	3.1	3.1	10
WY80	0.34	3.8	2.14911743	10
WY81	0.27	4	1.941457018	10
WY82	0.31	2.6	1.246164206	10
WY83	2	3	2.527978744	10
WY84	1.5	3.1	2.479640358	10
WY85	0.71	2	1.370145272	10
WY86	0.22	2	0.942684386	10
WY87	0.18	1.8	0.652945552	10
WY88	0.29	1.5	0.907097722	10
WY89	0.24	1.6	0.899398009	10
WY90	0.3	1.6	1.048751055	10
WY91	0.84	1.5	1.095805724	10
AVG			1.544608172	

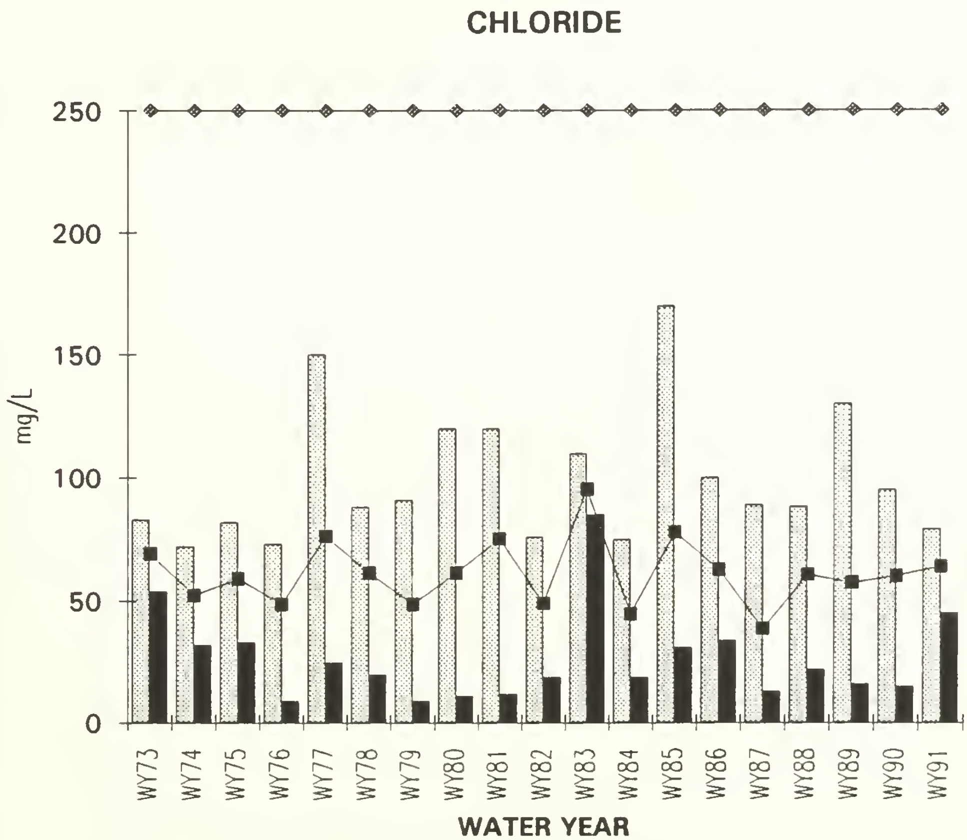


	MIN	MAX	MEAN
WY73	0.79	1.8	1.213335632
WY74	0.17	1.7	0.853156634
WY75	0.57	1.6	1.035712621
WY76	0.64	1.8	1.082023439
WY77	0.04	4.8	1.305303588
WY78	0.72	12	2.550016182
WY79	0.06	3.9	0.933408664
WY80	0.55	3.8	1.241605844
WY81	0.04	2.2	0.90271401
WY82	0.18	0.75	0.381712901
WY83	0.53	0.99	0.779775919
WY84	0.2	1	0.651368449
WY85	0.16	0.24	0.190155973
WY86	0.1	0.23	0.168983314
WY87	0.08	0.19	0.128611269
WY88	0.06	0.22	0.131950193
WY89	0.12	1.1	0.204073527
WY90	0.13	0.26	0.192575055
WY91	0.11	0.21	0.144954623
AVG			0.741654623

HARDNESS

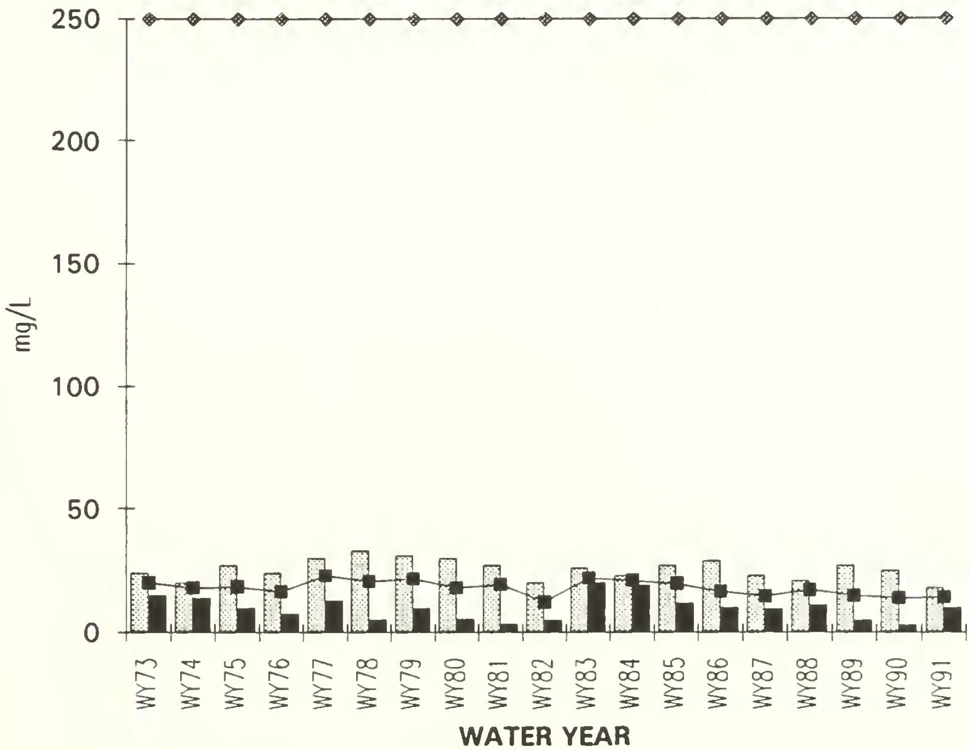


	MIN	MAX	MEAN	GOAL
WY73	51	72	60.99352843	80
WY74	40	64	51.9229399	80
WY75	29	76	55.07864782	80
WY76	24	67	49.28468022	80
WY77	32	110	66.15083061	80
WY78	21	78	58.18454643	80
WY79	9	80	48.8496604	80
WY80	14	94	55.61129807	80
WY81	12	94	63.88515489	80
WY82	22	71	46.93390165	80
WY83	71	91	79.68704834	80
WY84	58	110	75.58261144	80
WY85	37	120	70.15495794	80
WY86	9	82	48.35732982	80
WY87	18	75	40.26474287	80
WY88	22	75	56.64169033	80
WY89	17	110	53.85347433	80
WY90	15	89	56.07557472	80
WY91	46	71	59.83376879	80
AVG			57.755073	

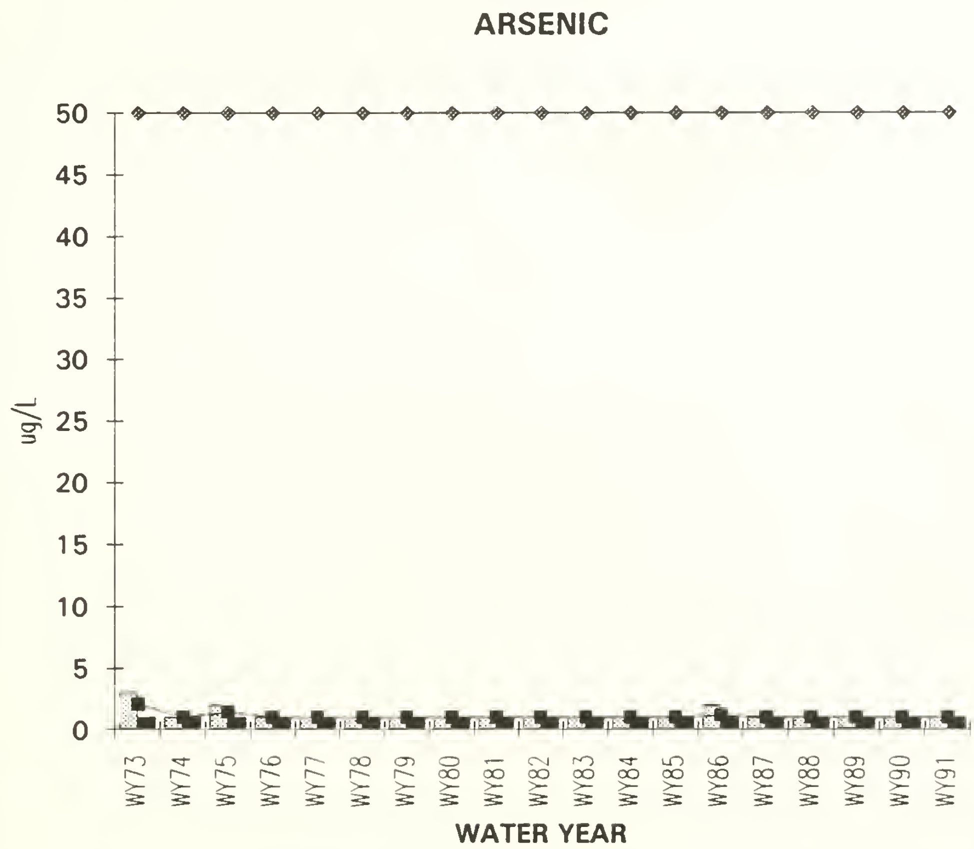


	MIN	MAX	MEAN	SMCL
WY73	54	83	68.83441595	250
WY74	32	72	52.39581878	250
WY75	33	82	59.06257693	250
WY76	9	73	48.74909718	250
WY77	25	150	76.18385127	250
WY78	20	88	61.38792273	250
WY79	9	91	48.55598698	250
WY80	11	120	61.41274827	250
WY81	12	120	75.19411545	250
WY82	19	76	48.834382	250
WY83	85	110	95.46605697	250
WY84	19	75	44.81002768	250
WY85	31	170	77.72544828	250
WY86	34	100	62.7256185	250
WY87	13	89	38.45464361	250
WY88	22	88	60.52205131	250
WY89	16	130	57.26530343	250
WY90	15	95	60.05085911	250
WY91	45	79	64.0906654	250
AVG			61.14324157	

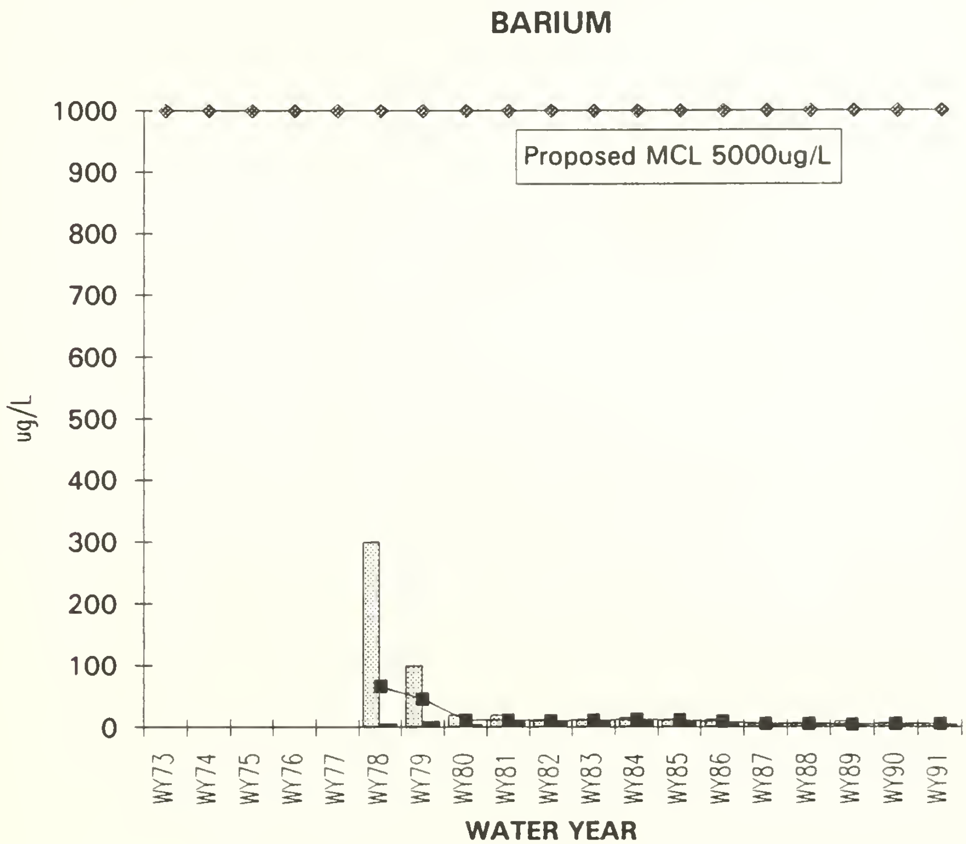
SULFATE



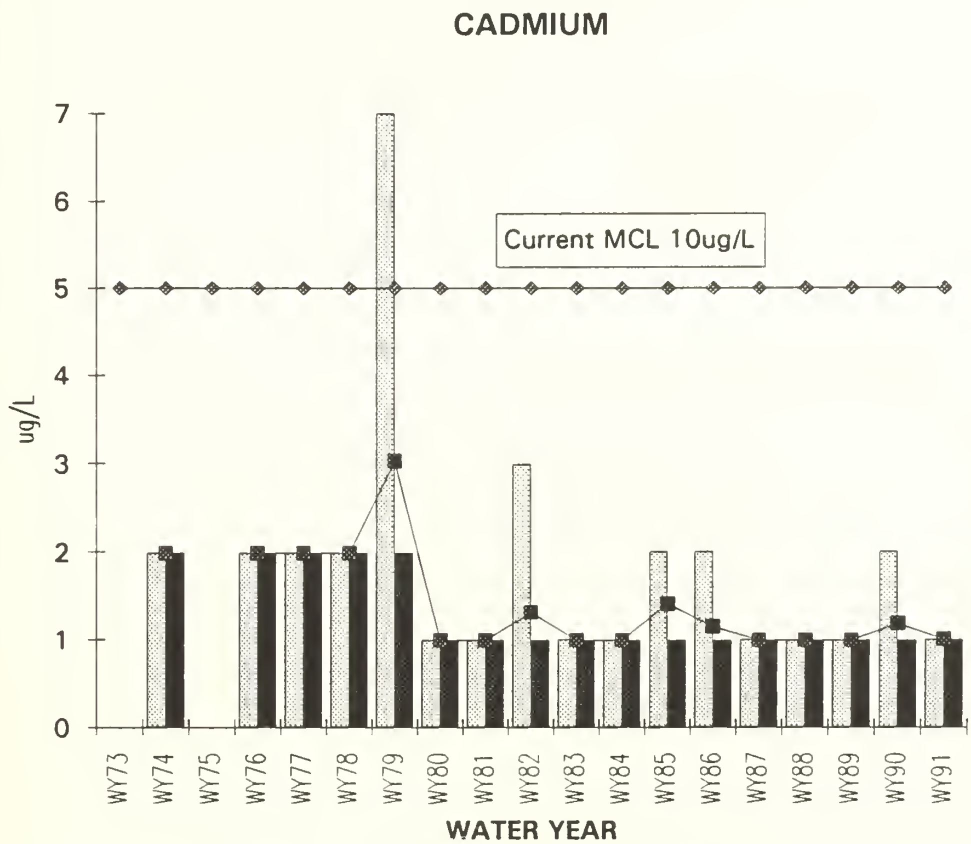
	MIN	MAX	MEAN	SMCL
WY73	15	24	20.18994032	250
WY74	14	20	18.04857118	250
WY75	9.9	27	18.45878699	250
WY76	7.4	24	16.55682689	250
WY77	13	30	22.87778212	250
WY78	5.1	33	20.64128707	250
WY79	9.8	31	21.56285409	250
WY80	5.4	30	18.09343461	250
WY81	3.2	27	19.26574735	250
WY82	4.99	20	12.45471203	250
WY83	20	26	21.90620723	250
WY84	19	23	20.94353318	250
WY85	12	27	19.70308238	250
WY86	10	29	16.55503082	250
WY87	9.5	23	14.63584104	250
WY88	11	21	17.30558031	250
WY89	4.99	27	14.92623505	250
WY90	2.9	25	13.93693282	250
WY91	10	18	14.08678485	250
AVG			18.00785107	



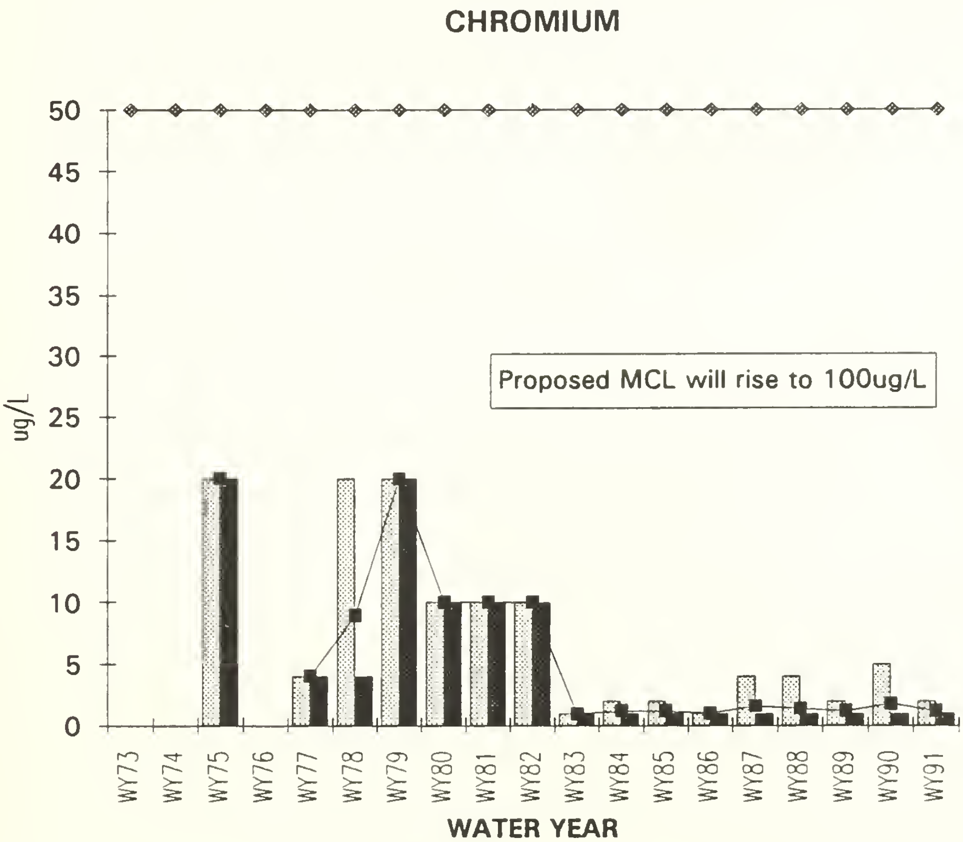
	MIN	MAX	MEAN	MCL
WY73	1	3	2.080083823	50
WY74	0.99	1	0.994987437	50
WY75	0.99	2	1.410664692	50
WY76	0.99	0.99	0.992490586	50
WY77	0.99	1	0.992490586	50
WY78	0.99	1	0.994987437	50
WY79	0.99	1	0.993987944	50
WY80	1	1	1	50
WY81	1	1	1	50
WY82	0.99	1	0.994987437	50
WY83	0.99	0.99	0.99	50
WY84	0.99	1	0.992490586	50
WY85	0.99	0.99	0.99	50
WY86	0.99	2	1.139499542	50
WY87	0.99	0.99	0.99	50
WY88	0.99	0.99	0.99	50
WY89	0.99	0.99	0.99	50
WY90	0.99	1	0.992490586	50
WY91	1	1	1	50
AVG			1.08048214	



	MIN	MAX	MEAN	MCL
WY73	0	0		1000
WY74	0	0		1000
WY75	0	0		1000
WY76	0	0		1000
WY77	0	0		1000
WY78	6	300	65.1323	1000
WY79	10	99.99	45.72776	1000
WY80	4.99	20	11.88612065	1000
WY81	10	20	11.89207115	1000
WY82	9	13	11.14782001	1000
WY83	11	13	11.97911219	1000
WY84	11	16	13.11310345	1000
WY85	11	13	11.72134617	1000
WY86	4.99	13	9.328554551	1000
WY87	4	6	5.241482788	1000
WY88	4.99	7	5.954910953	1000
WY89	1.99	10	4.940560457	1000
WY90	4.99	7	5.954910953	1000
WY91	4.99	6	5.729788273	1000
AVG			15.69641726	

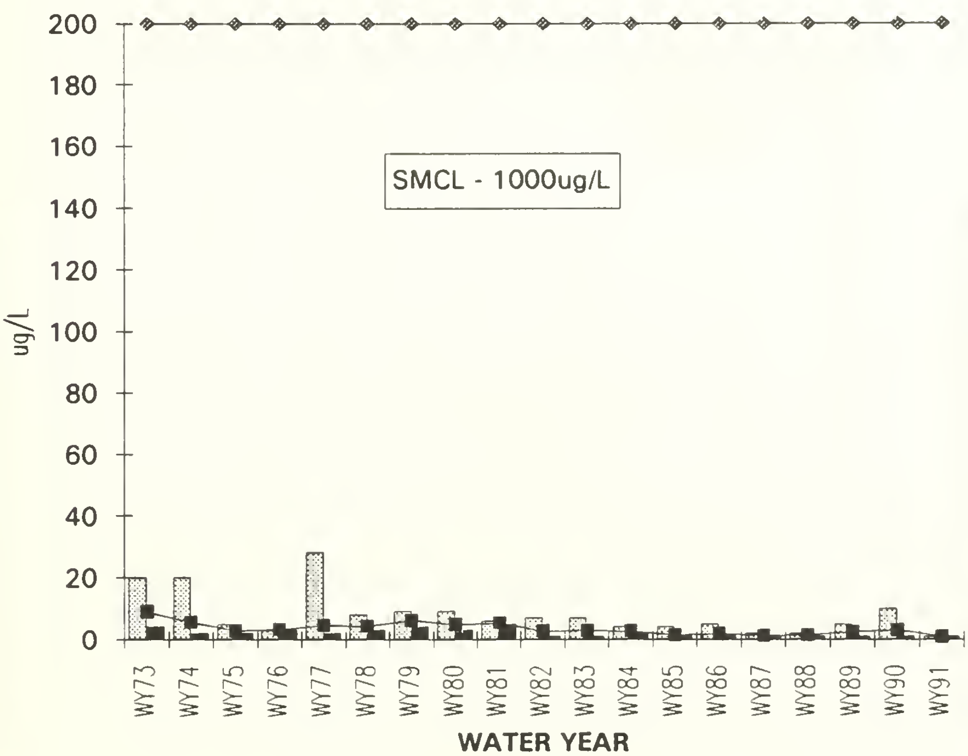


	MIN	MAX	MEAN	PMCL
WY73	0	0		5
WY74	1.99	1.99	1.99	5
WY75	0	0		5
WY76	1.99	1.99	1.99	5
WY77	1.99	1.99	1.99	5
WY78	1.99	1.99	1.99	5
WY79	1.99	7	3.023608738	5
WY80	0.99	0.99	0.99	5
WY81	0.99	0.99	0.99	5
WY82	0.99	2.99	1.305101212	5
WY83	0.99	1	0.992490586	5
WY84	0.99	0.99	0.99	5
WY85	0.99	2	1.407124728	5
WY86	0.99	2	1.139499542	5
WY87	0.99	1	0.993322173	5
WY88	0.99	0.99	0.99	5
WY89	0.99	0.99	0.99	5
WY90	0.99	2	1.180276866	5
WY91	1	1	1	5
AVG			1.408907285	



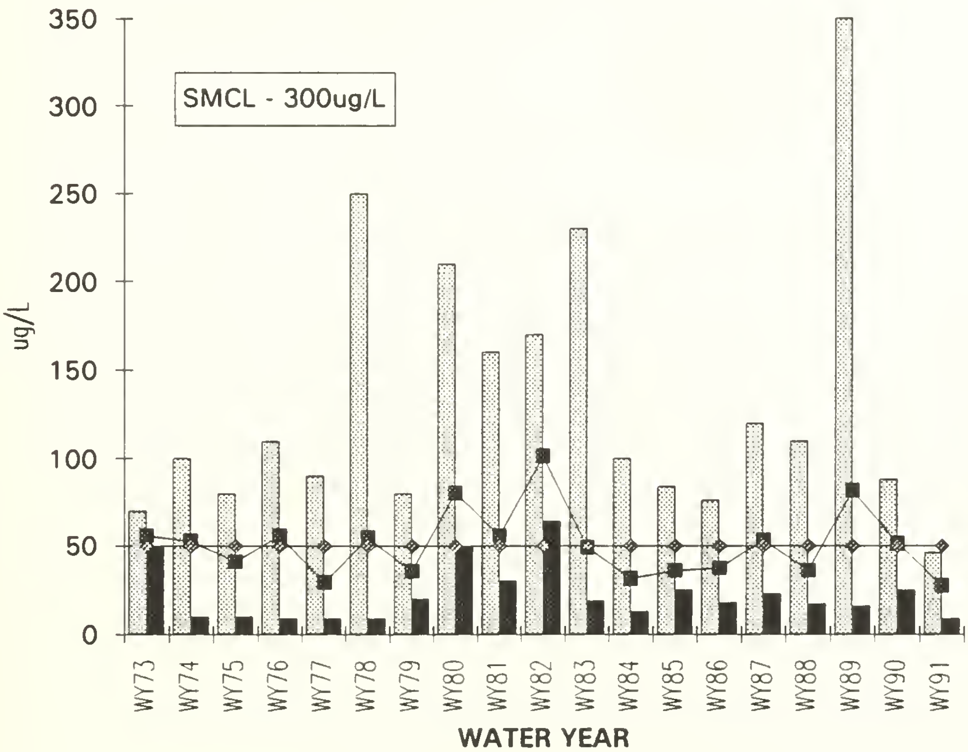
	MIN	MAX	MEAN	MCL
WY73	0	0		50
WY74	0	0		50
WY75	19.99	19.99	19.99	50
WY76	0	0		50
WY77	4	4	4	50
WY78	4	19.99	8.942036	50
WY79	19.99	19.99	19.99	50
WY80	10	10	10	50
WY81	10	10	10	50
WY82	9.99	10	9.992499062	50
WY83	0.99	0.99	0.99	50
WY84	0.99	2	1.186222883	50
WY85	0.99	2	1.18324614	50
WY86	0.99	1	0.993987944	50
WY87	0.99	4	1.576800662	50
WY88	0.99	4	1.407124728	50
WY89	0.99	2	1.186222883	50
WY90	0.99	4.99	1.768480326	50
WY91	1	2	1.189207115	50
AVG			5.899739234	

COPPER

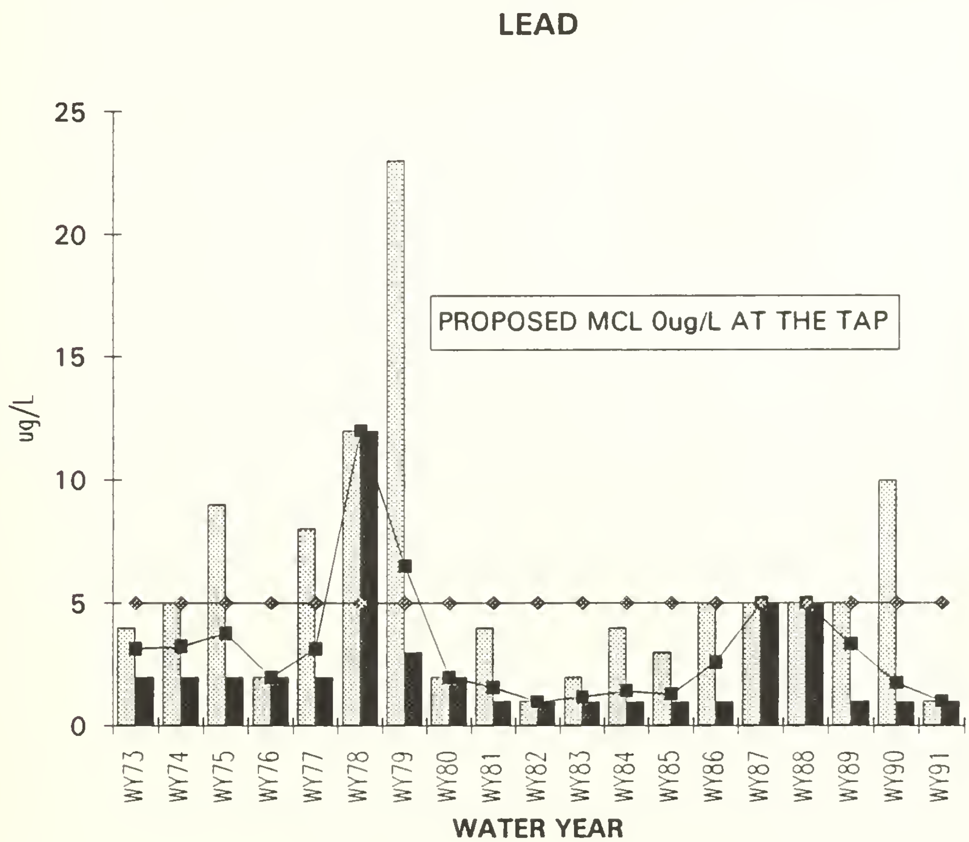


	MIN	MAX	GEOMEAN	GOAL
WY73	4	19.99	8.961315	199.99
WY74	2	19.99	5.510066	199.99
WY75	1.99	4.99	2.774801933	199.99
WY76	3	3	3.223709795	199.99
WY77	2	28	4.600653268	199.99
WY78	3	8	4.353697601	199.99
WY79	4	9	6.043800271	199.99
WY80	3	9	4.69525374	199.99
WY81	4.99	6	5.225323969	199.99
WY82	1	7	2.545729895	199.99
WY83	1	7	2.817313247	199.99
WY84	2	4	2.632148026	199.99
WY85	1	4	1.414213562	199.99
WY86	0.99	4.99	1.812534097	199.99
WY87	0.99	2	1.255707236	199.99
WY88	0.99	2	1.410664692	199.99
WY89	1	4.99	2.513608482	199.99
WY90	1	9.99	2.989949608	199.99
WY91	1	1	1	199.99
AVG			3.462131075	

IRON

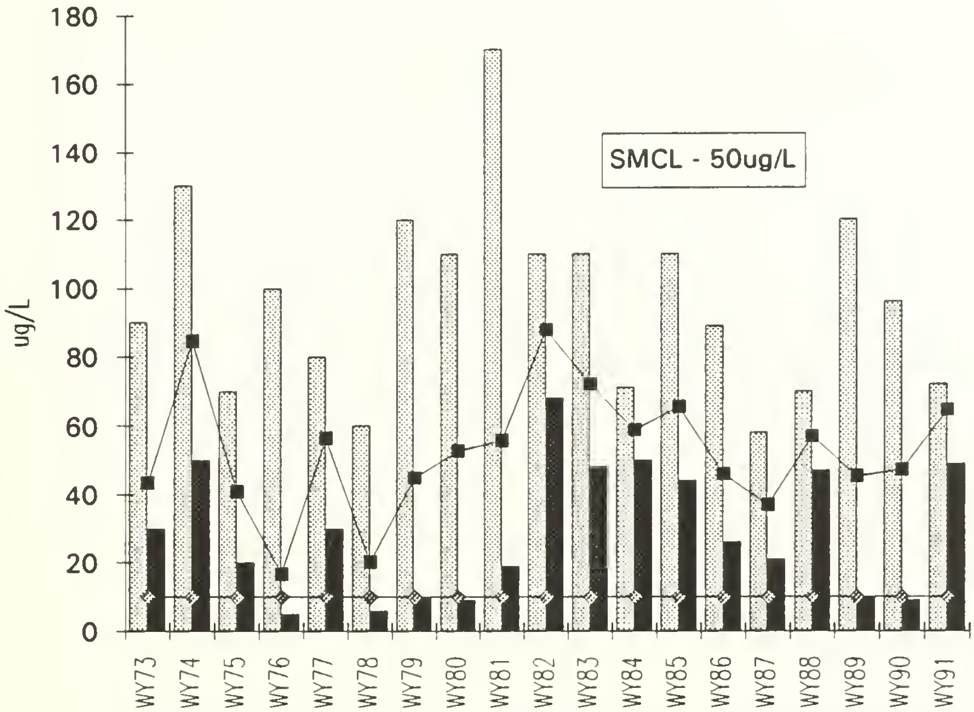


	MIN	MAX	MEAN	STD/GOAL
WY73	50	70	55.9344471	49.99
WY74	9.99	100	52.51670428	49.99
WY75	9.99	80	40.8960045	49.99
WY76	9	110	55.72321476	49.99
WY77	9	90	29.22011239	49.99
WY78	9	250	54.42667222	49.99
WY79	20	80	35.65204916	49.99
WY80	50	210	80.50304776	49.99
WY81	30	160	55.9394061	49.99
WY82	64	170	101.486524	49.99
WY83	19	230	48.83971324	49.99
WY84	13	100	31.73287995	49.99
WY85	25	84	36.00205744	49.99
WY86	18	76	37.28435074	49.99
WY87	23	120	53.34461567	49.99
WY88	17	110	35.8569601	49.99
WY89	16	350	81.29627702	49.99
WY90	25	88	51.33627062	49.99
WY91	9	46	27.7191537	49.99
AVG			50.82686635	

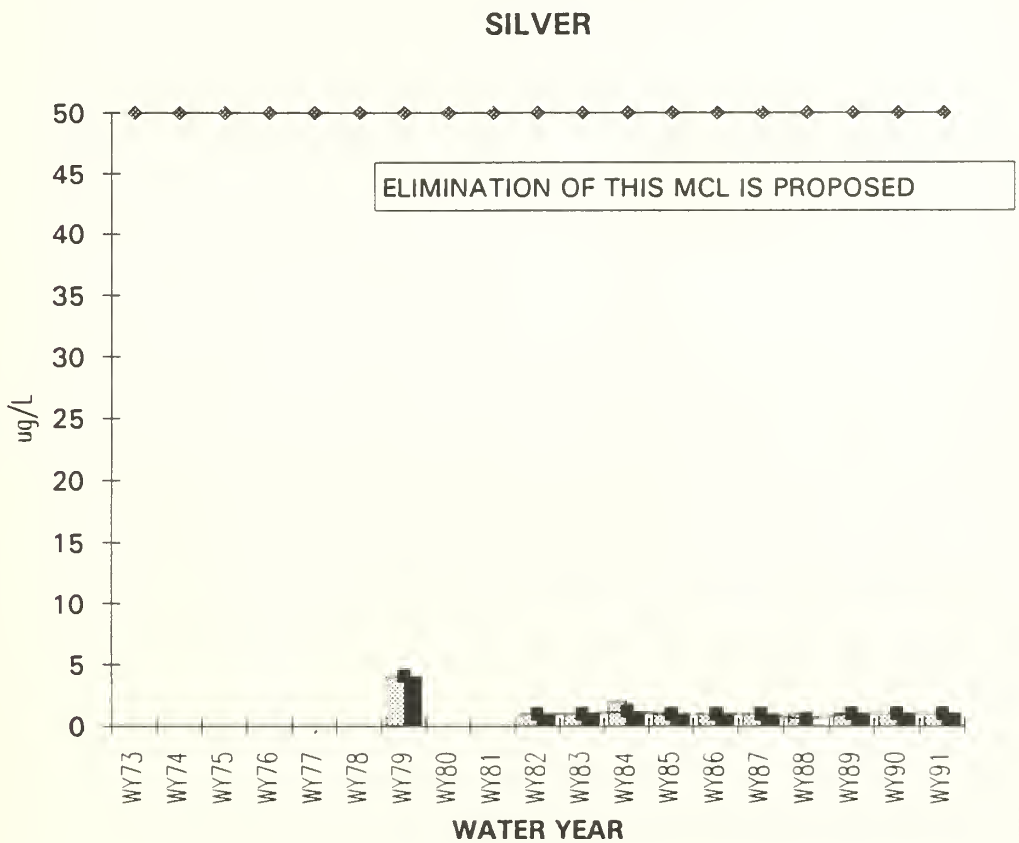


	MIN	MAX	MEAN	MCL
WY73	1.99	4	3.169501924	5
WY74	2	5	3.245342223	5
WY75	1.99	9	3.773453016	5
WY76	1.99	1.99	1.99	5
WY77	1.99	8	3.169501924	5
WY78	12	12	12	5
WY79	3	23	6.510830072	5
WY80	2	2	2	5
WY81	1	4	1.587401052	5
WY82	0.99	1	0.992490586	5
WY83	0.99	2	1.18324614	5
WY84	0.99	4	1.410664692	5
WY85	0.99	3	1.306191068	5
WY86	0.99	4.99	2.618106846	5
WY87	4.99	4.99	4.99	5
WY88	4.99	4.99	4.99	5
WY89	1	4.99	3.338684718	5
WY90	0.99	9.99	1.768923165	5
WY91	1	1	1	5
AVG			3.212859864	

MANGANESE

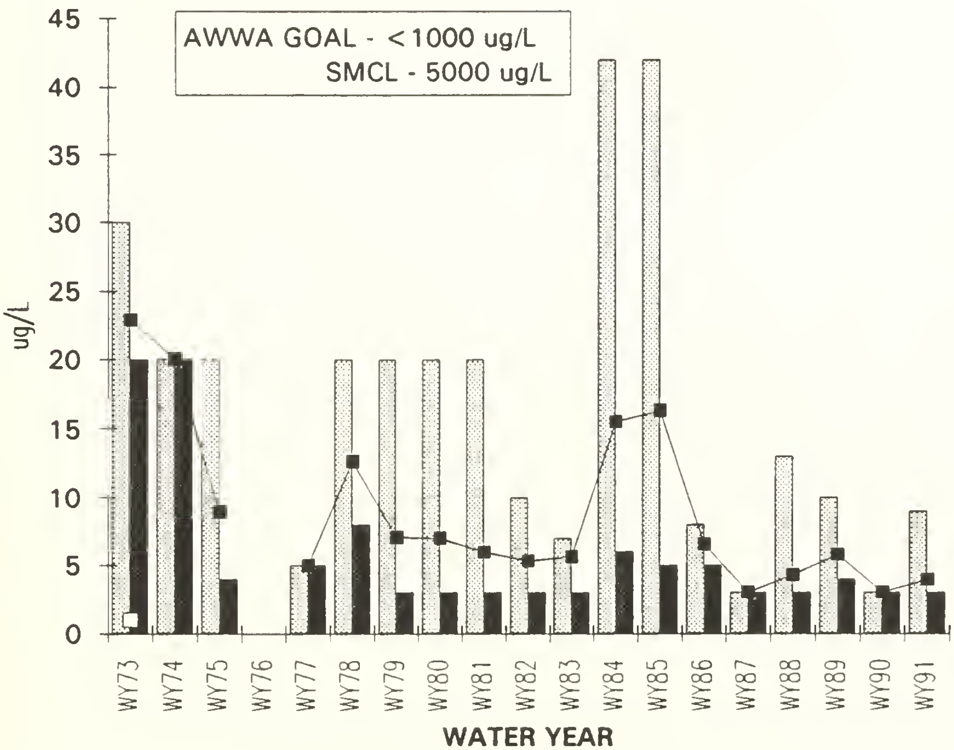


	MIN	MAX	MEAN	GOAL
WY73	30	90	43.26748711	9.99
WY74	50	130	84.57902358	9.99
WY75	20	70	40.95727209	9.99
WY76	4.99	100	16.71718778	9.99
WY77	30	80	56.34626495	9.99
WY78	6	60	20.06220915	9.99
WY79	9.99	120	44.7679903	9.99
WY80	9	110	52.54501011	9.99
WY81	19	170	55.79315803	9.99
WY82	68	110	87.86435612	9.99
WY83	48	110	71.93006793	9.99
WY84	50	71	58.7462595	9.99
WY85	44	110	65.55614874	9.99
WY86	26	89	46.00337571	9.99
WY87	21	58	36.82508136	9.99
WY88	47	70	56.91760865	9.99
WY89	10	120	45.28311936	9.99
WY90	9	96	47.16395664	9.99
WY91	49	72	64.48091092	9.99
AVG			52.41086779	

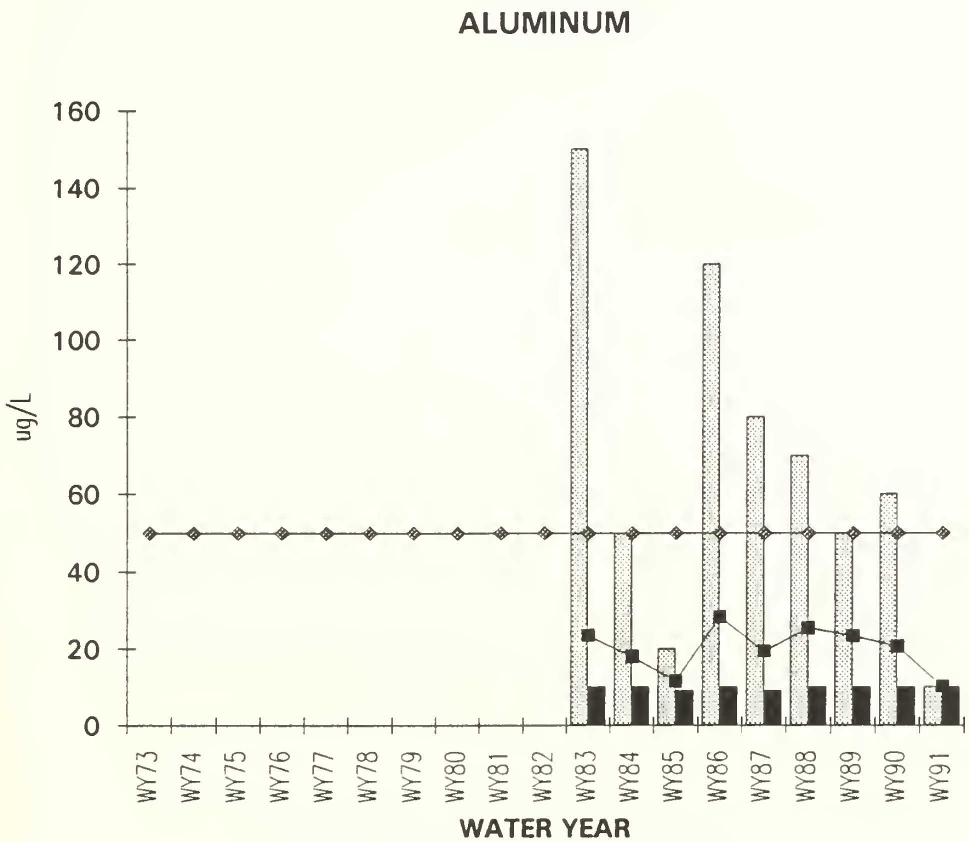


	MIN	MAX	MEAN	MCL
WY73	0	0		50
WY74	0	0		50
WY75	0	0		50
WY76	0	0		50
WY77	0	0		50
WY78	0	0		50
WY79	4	4	4	50
WY80	0	0		50
WY81	0	0		50
WY82	0.99	0.99	0.99	50
WY83	0.99	0.99	0.99	50
WY84	0.99	2	1.180276866	50
WY85	0.99	0.99	0.99	50
WY86	0.99	0.99	0.99	50
WY87	0.99	0.99	0.99	50
WY88	0.1	0.99	0.558118471	50
WY89	0.99	1	0.992490586	50
WY90	1	1	1	50
WY91	1	1	1	50
AVG			1.243716902	

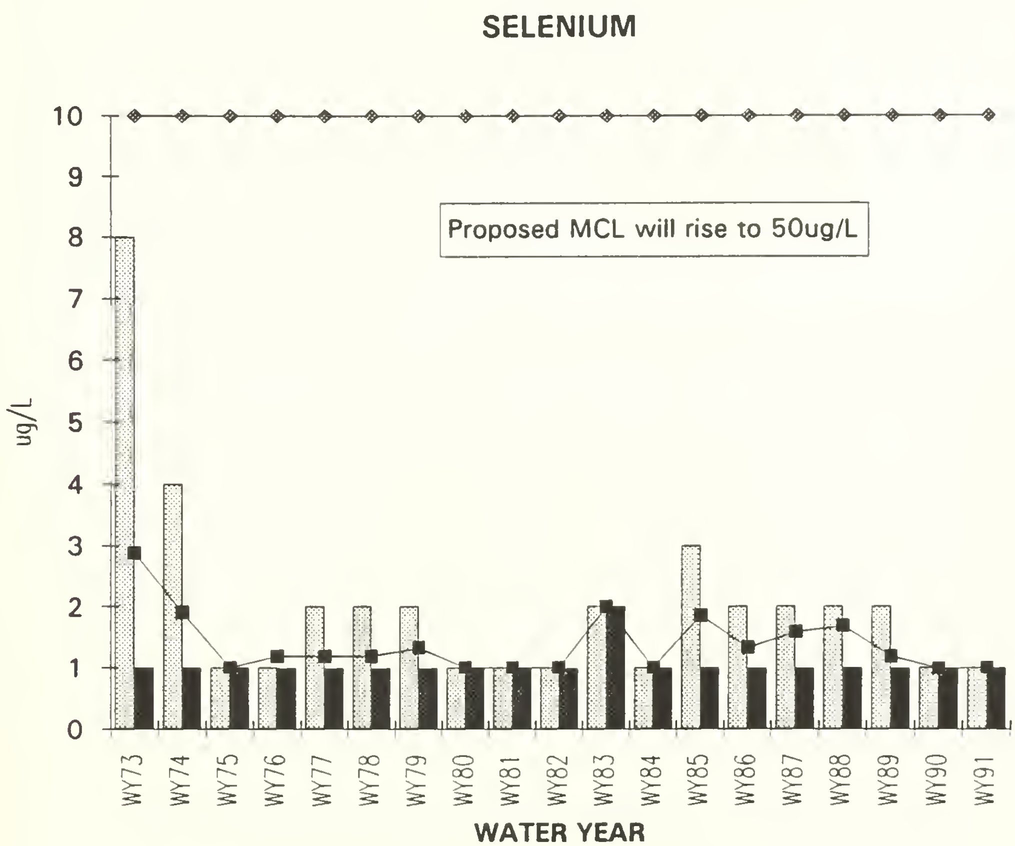
ZINC



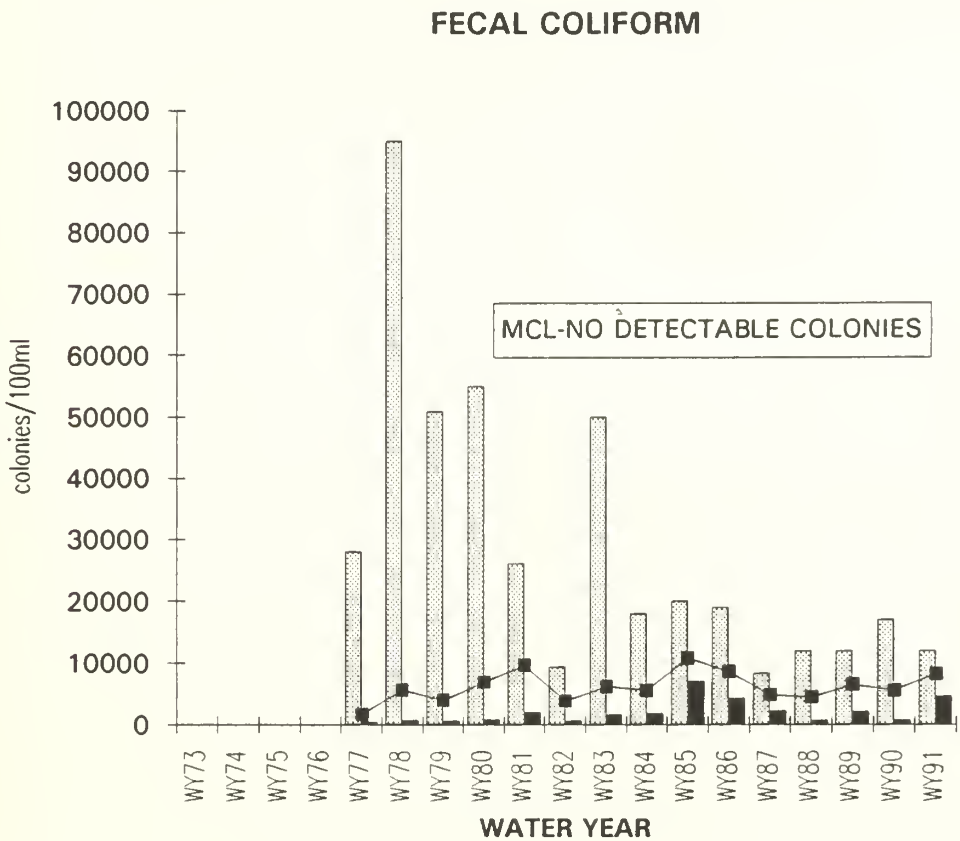
	MIN	MAX	GEOMEAN
WY73	19.99	30	22.88665
WY74	19.99	19.99	19.99
WY75	4	20	8.94427191
WY76	0	0	
WY77	4.99	4.99	4.99
WY78	8	19.99	12.64595
WY79	2.99	19.99	7.104689
WY80	2.99	20	6.993430992
WY81	2.99	20	5.952921007
WY82	2.99	10	5.303841999
WY83	2.99	7	5.659021281
WY84	6	42	15.48224184
WY85	4.99	42	16.2535607
WY86	4.99	8	6.51489728
WY87	2.99	2.99	2.99
WY88	2.99	13	4.317568428
WY89	4	10	5.785015217
WY90	2.99	2.99	2.99
WY91	3	9	3.948222039
AVG			8.819571205



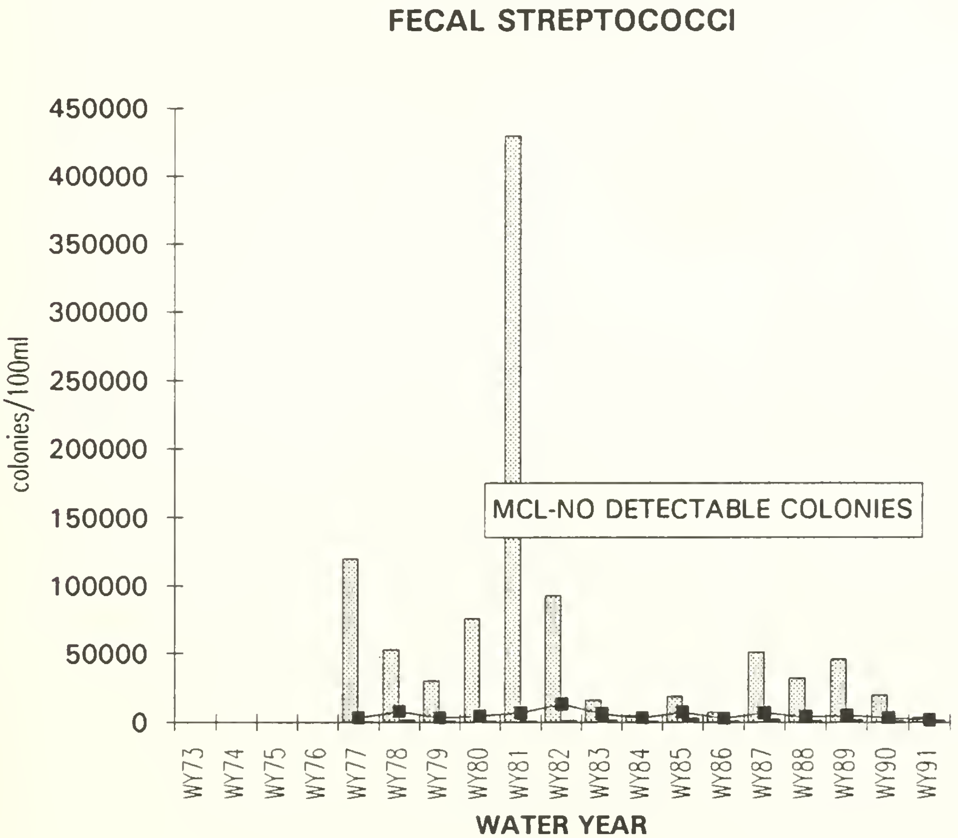
	MIN	MAX	MEAN	GOAL
WY73	0	0		50
WY74	0	0		50
WY75	0	0		50
WY76	0	0		50
WY77	0	0		50
WY78	0	0		50
WY79	0	0		50
WY80	0	0		50
WY81	0	0		50
WY82	0	0		50
WY83	9.99	150	23.39762013	50
WY84	9.99	50	17.77834673	50
WY85	9	20	11.57712894	50
WY86	9.99	120	28.24669227	50
WY87	9	80	19.30978769	50
WY88	9.99	70	25.45093224	50
WY89	9.99	50	23.2001542	50
WY90	9.99	60	20.59252009	50
WY91	10	10	10	50
AVG			19.95035359	



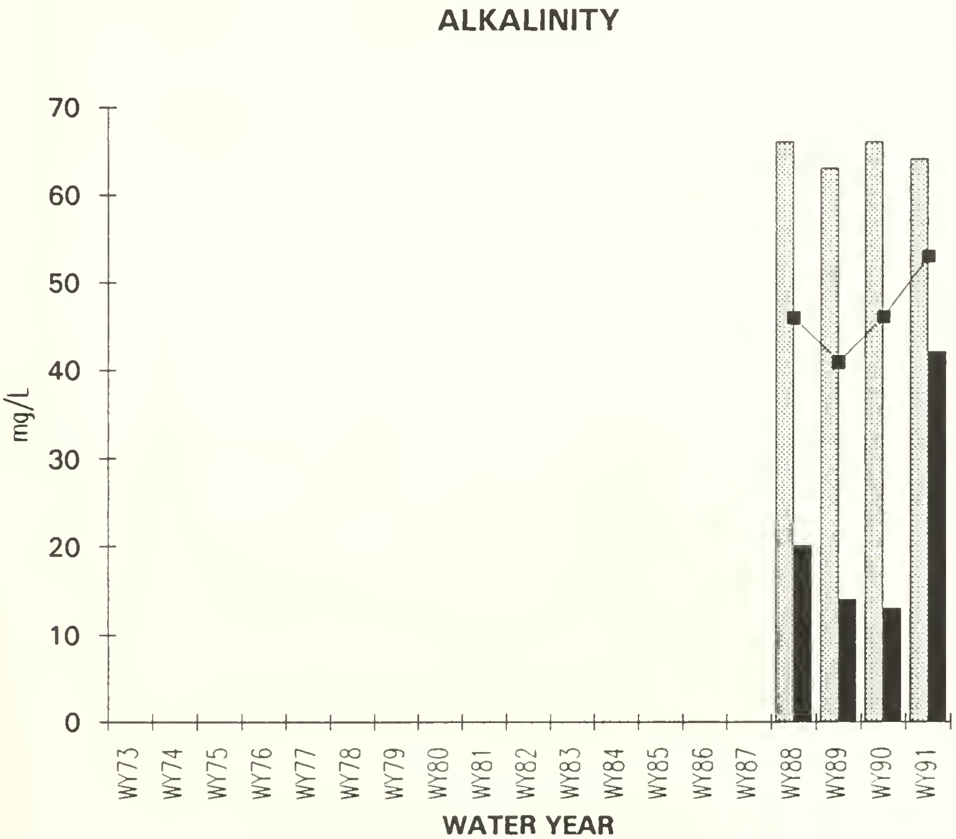
	MIN	MAX	MEAN	MCL
WY73	1	8	2.884499141	10
WY74	1	4	1.906368586	10
WY75	1	1	1	10
WY76	0.99	1	1.186222883	10
WY77	0.99	2	1.18324614	10
WY78	0.99	2	1.18324614	10
WY79	0.99	2	1.316858275	10
WY80	1	1	1	10
WY81	1	1	1	10
WY82	0.99	1	0.99749057	10
WY83	2	2	2	10
WY84	0.99	1	0.99749057	10
WY85	1	3	1.861209718	10
WY86	0.99	2	1.316858275	10
WY87	0.99	2	1.582091979	10
WY88	1	2	1.681792831	10
WY89	0.99	2	1.186222883	10
WY90	0.99	1	0.994987437	10
WY91	1	1	1	10
AVG			1.383083443	



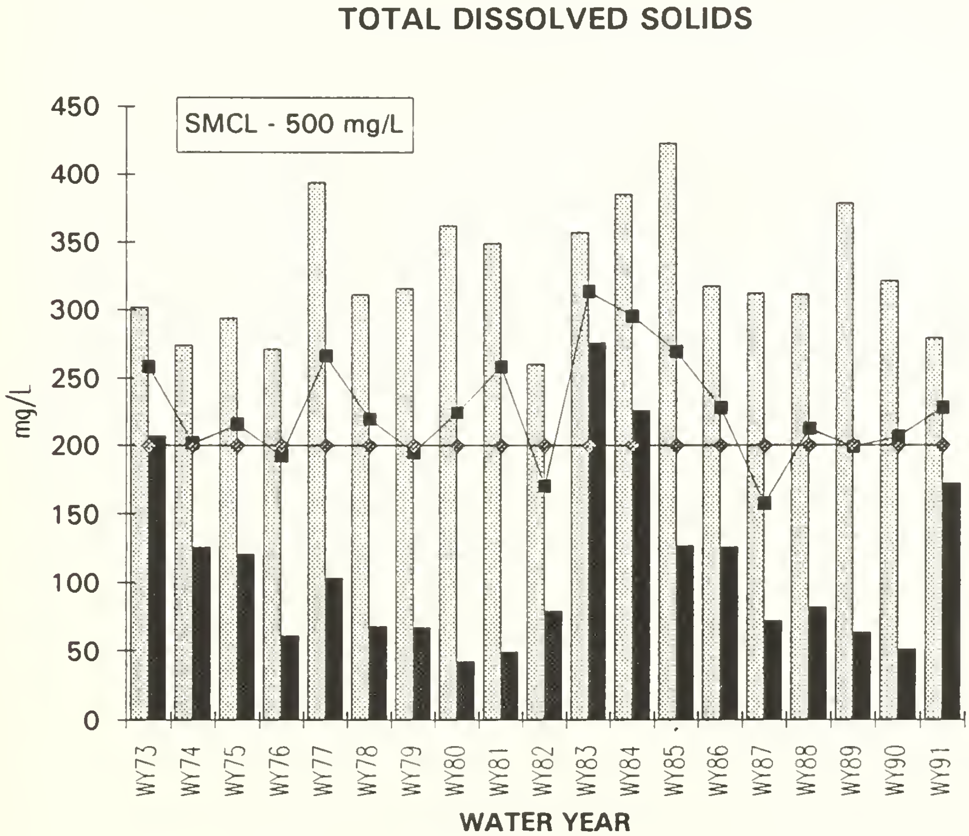
	MIN	MAX	MEAN
WY73	0	0	
WY74	0	0	
WY75	0	0	
WY76	0	0	
WY77	420	28000	1610.293543
WY78	700	95000	5670.082738
WY79	560	51000	3864.164218
WY80	780	55000	6869.981363
WY81	2000	26000	9639.086755
WY82	600	9400	3805.894133
WY83	1600	50000	6122.317506
WY84	1800	18000	5546.584821
WY85	7000	20000	10866.67913
WY86	4300	19000	8521.710927
WY87	2200	8400	4860.860673
WY88	660	12000	4396.36138
WY89	2100	12000	6520.680014
WY90	740	17000	5518.117739
WY91	4600	12000	8220.427509
AVG			6135.549497



	MIN	MAX	MEAN
WY73	0	0	
WY74	0	0	
WY75	0	0	
WY76	0	0	
WY77	530	120000	3311.51306
WY78	1600	53000	7980.290722
WY79	770	30000	3214.821
WY80	880	76000	4679.11391
WY81	860	430000	7070.911
WY82	1100	93000	13410.09
WY83	1600	16000	5836.689984
WY84	920	4900	2995.532
WY85	3000	19000	7511.479825
WY86	960	7500	2764.466665
WY87	2000	51000	6786.813
WY88	1200	32000	3590.292
WY89	1700	46000	5078.636863
WY90	600	20000	3390.73907
WY91	1200	3700	1887.732
AVG			5300.608073

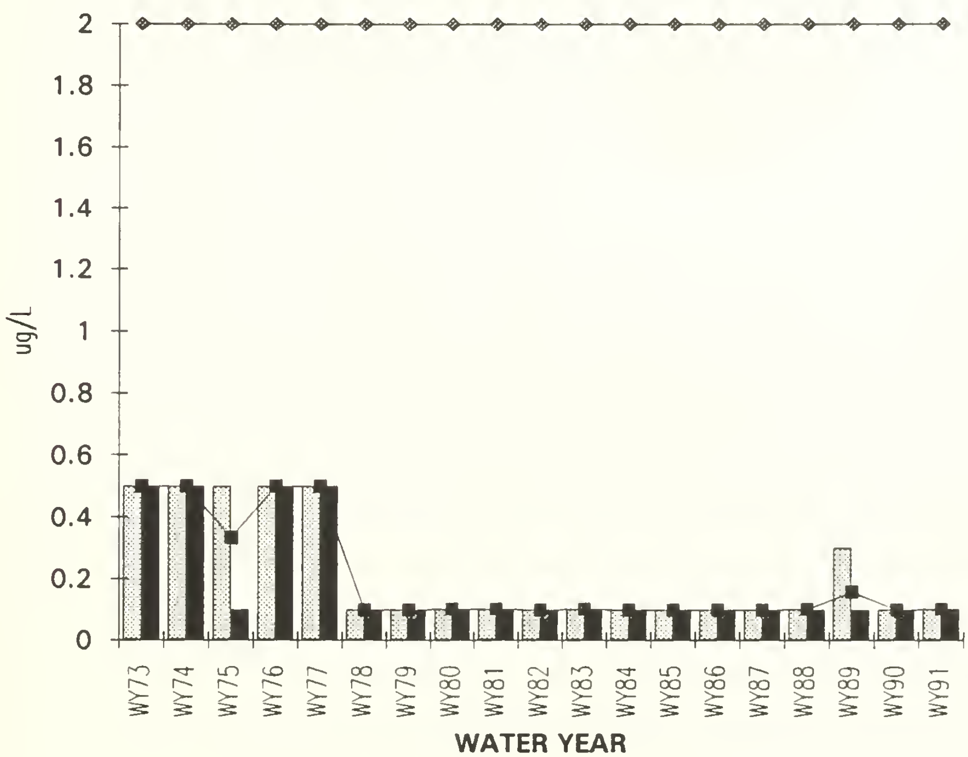


	MIN	MAX	MEAN
WY73	0	0	
WY74	0	0	
WY75	0	0	
WY76	0	0	
WY77	0	0	
WY78	0	0	
WY79	0	0	
WY80	0	0	
WY81	0	0	
WY82	0	0	
WY83	0	0	
WY84	0	0	
WY85	0	0	
WY86	0	0	
WY87	0	0	
WY88	20	66	45.96797915
WY89	14	63	40.88036237
WY90	13	66	46.00319872
WY91	42	64	52.94747874
AVG			46.44975475

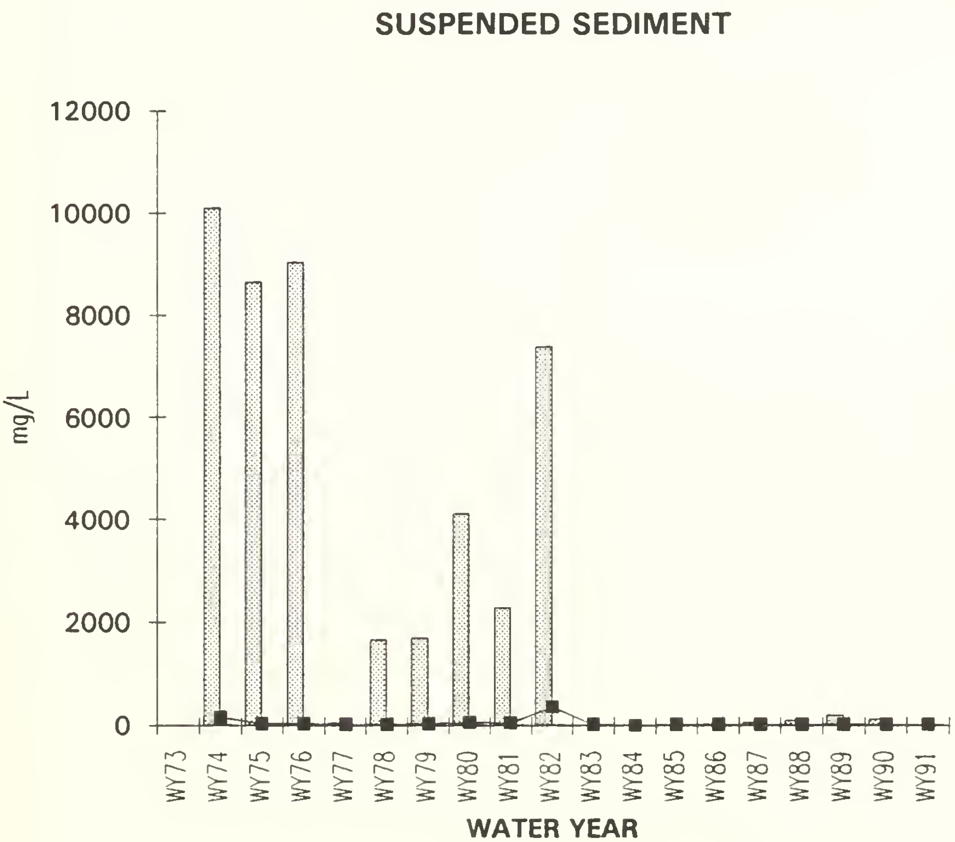


	MIN	MAX	MEAN	GOAL
WY73	207	302	258.2838188	200
WY74	126	274	201.6367186	200
WY75	121	294	215.1654018	200
WY76	61	271	192.1566322	200
WY77	103	394	266.0441478	200
WY78	68	311	219.6734108	200
WY79	67	316	194.8828132	200
WY80	42	362	224.0476133	200
WY81	49	349	258.2408323	200
WY82	79	260	170.2891234	200
WY83	276	357	313.0013611	200
WY84	226	385	295.2846223	200
WY85	127	423	269.0164111	200
WY86	126	317	227.8577099	200
WY87	72	312	157.3059933	200
WY88	82	311	212.1630804	200
WY89	63	378	198.7078752	200
WY90	51	321	206.5912006	200
WY91	172	279	227.7206738	200
AVG			226.7404968	

MERCURY

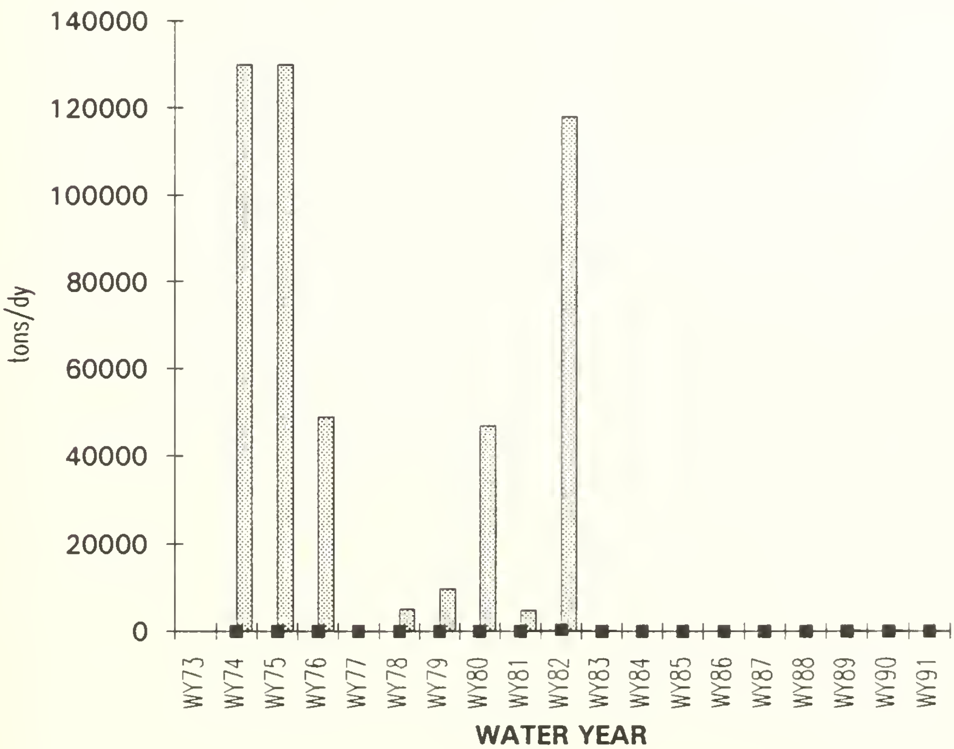


	MIN	MAX	MEAN	MCL
WY73	0.499	0.499	0.499	2
WY74	0.499	0.499	0.499	2
WY75	0.099	0.499	0.333030652	2
WY76	0.499	0.499	0.499	2
WY77	0.499	0.499	0.499	2
WY78	0.099	0.099	0.099	2
WY79	0.099	0.099	0.099	2
WY80	0.1	0.1	0.1	2
WY81	0.1	0.1	0.1	2
WY82	0.099	0.099	0.099	2
WY83	0.099	0.1	0.099249059	2
WY84	0.099	0.099	0.099	2
WY85	0.099	0.099	0.099	2
WY86	0.099	0.099	0.099	2
WY87	0.099	0.099	0.099	2
WY88	0.099	0.1	0.099249059	2
WY89	0.099	0.3	0.15572395	2
WY90	0.099	0.099	0.099	2
WY91	0.1	0.1	0.1	2
AVG			0.198697512	



	MIN	MAX	MEAN
WY73	0	0	
WY74	12	10100	153.1601239
WY75	6	8660	36.45189721
WY76	4.99	9050	39.17081788
WY77	6	43	13.1955377
WY78	10	1660	26.49425378
WY79	3	1700	32.00529682
WY80	4.99	4120	61.80672398
WY81	6	2280	46.07186852
WY82	4.99	7390	358.9195177
WY83	3	13	5.330160937
WY84	2	9	4.646206545
WY85	4	11	7.006164394
WY86	4	19	7.461886901
WY87	6	56	13.92801818
WY88	6	92	15.35668888
WY89	8	202	21.96522268
WY90	4.99	121	14.24868737
WY91	3	9	5.661873421
AVG			47.93783038

SEDIMENT DISCHARGE



	MIN	MAX	MEAN
WY73	0	0	
WY74	0.45	130000	30.62455462
WY75	0.05	130000	4.292957014
WY76	0.11	48900	3.618908166
WY77	0.13	6.4	0.439740576
WY78	0.03	5110	0.87504411
WY79	0.09	9690	2.14990532
WY80	0.14	46900	18.81537303
WY81	0.21	4800	5.413589128
WY82	0.5	118000	257.1200297
WY83	0.18	32	0.731450081
WY84	0.06	0.59	0.176596864
WY85	0.06	1.7	0.257721664
WY86	0.17	3	0.432773051
WY87	0.26	15	1.296733269
WY88	0.19	24	1.167810075
WY89	0.78	88	2.278475943
WY90	0.26	38	1.377877956
WY91	0.24	0.68	0.413453078
AVG			18.41572187